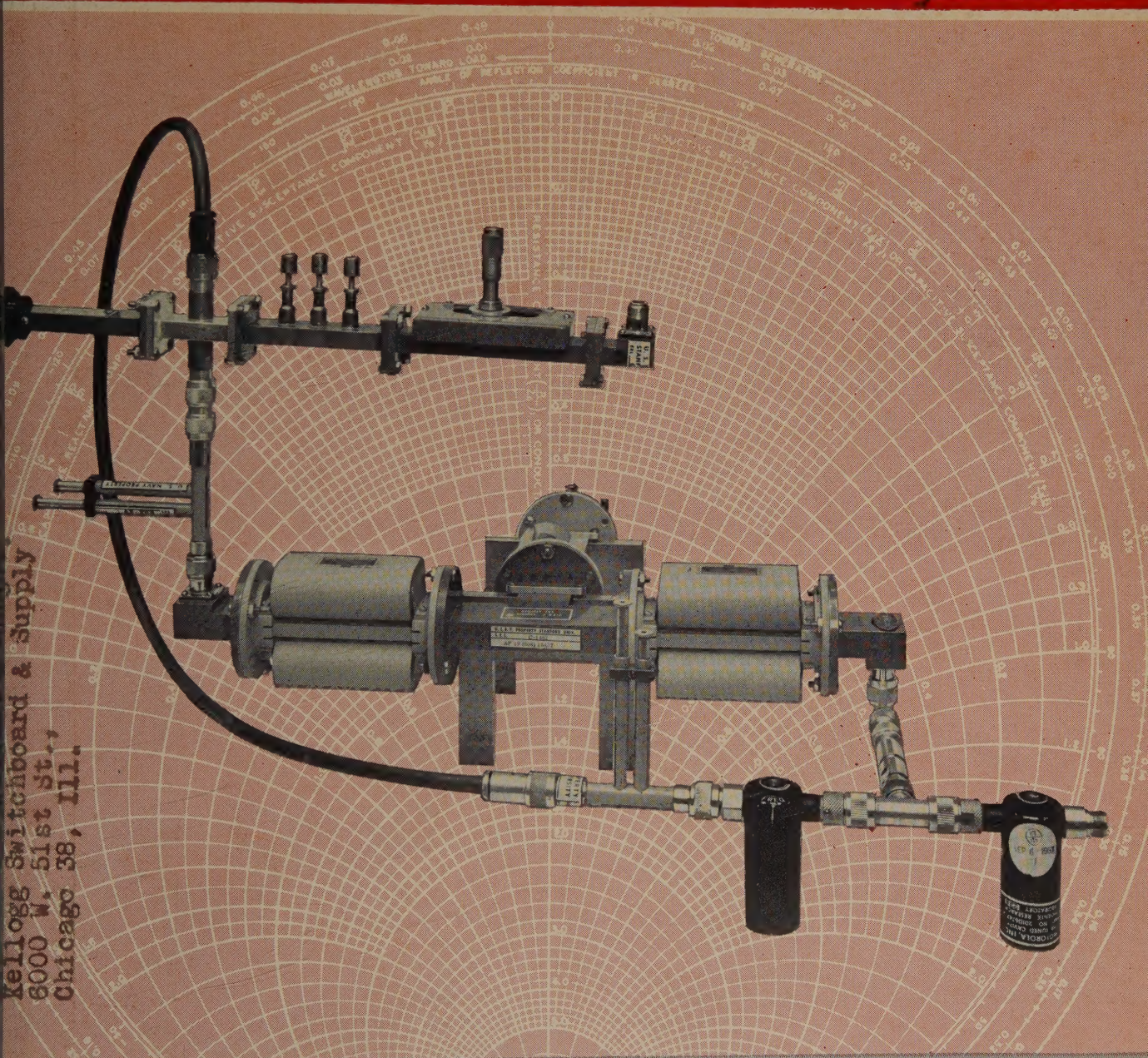
MARCH 1959
VOL. 2 • NO. 3

- Heffner — Masers and Parametric Amplifiers
- Ewen — Maser Systems Analysis
- Whitmer — Ionized Media II
- Raytheon — Company Profile, Part I

the microwave journal



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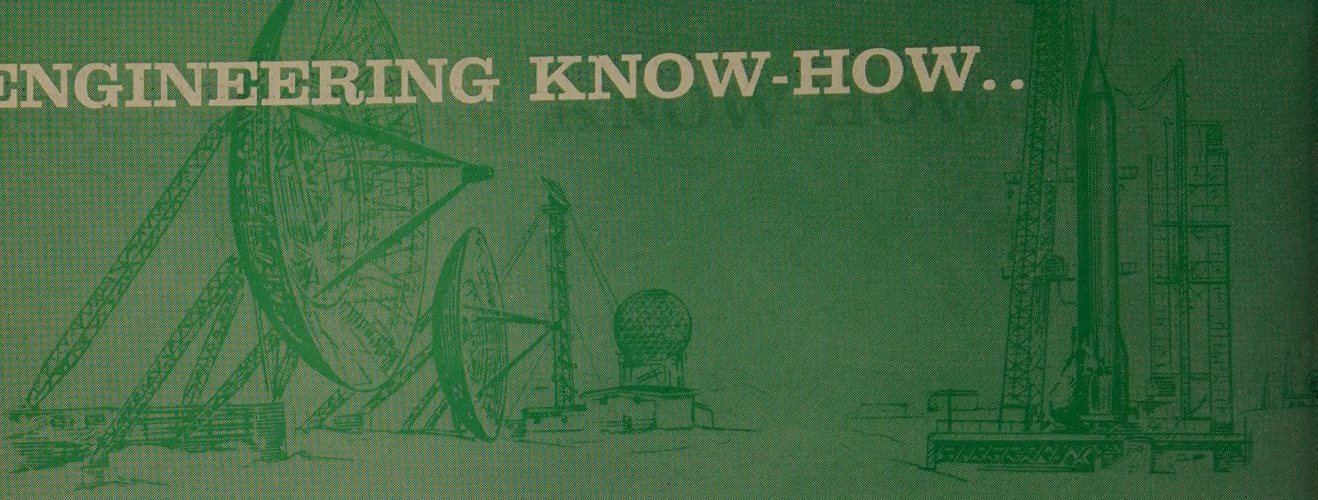
NEXT ISSUE — GASEOUS SCANNERS — NEW KLYSTRON AMPLIFIER
NOISE FIGURE MEASUREMENTS

ENGINEERING KNOW-HOW..



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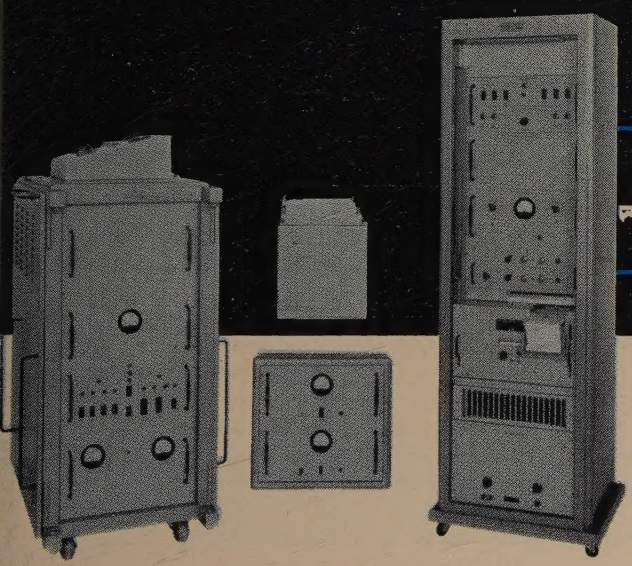
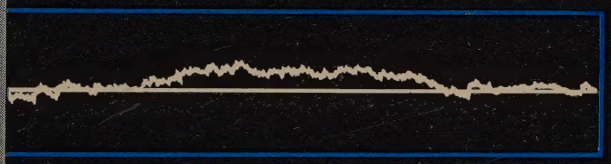


Maximum antenna temperature for this observation: 0.04° Kelvin
(signal level 100,000 times below the system noise level)



Saturn Photo Courtesy of Yerkes Observatory

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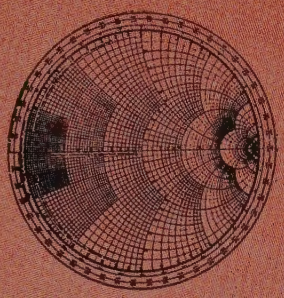

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COVER PICTURE

A two-stage ladder-type parametric upconverter. The first stage, at the right, is a conventional parametric oscillator pumped at 7.0 Kmc/s and oscillating at 3.1 and 3.9 Kmc/s. In the second stage at the left, the 3.9 Kmc/s oscillations are upconverted with gain to 7.0 + 3.9 = 10.9 Kmc/s. Power from the single pump source is split and used to drive both stages. Hopefully, further stages in the ladder could be added indefinitely. (Stanford.)

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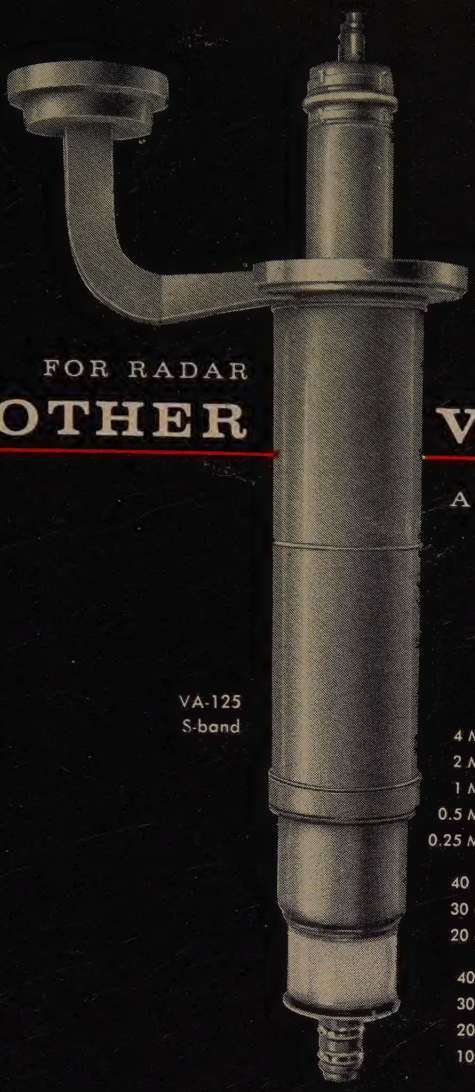

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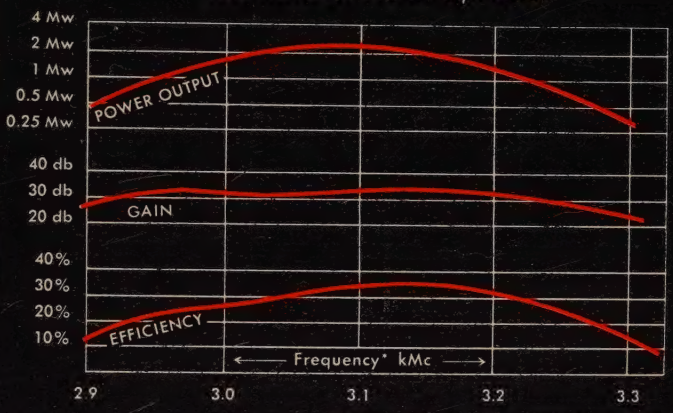

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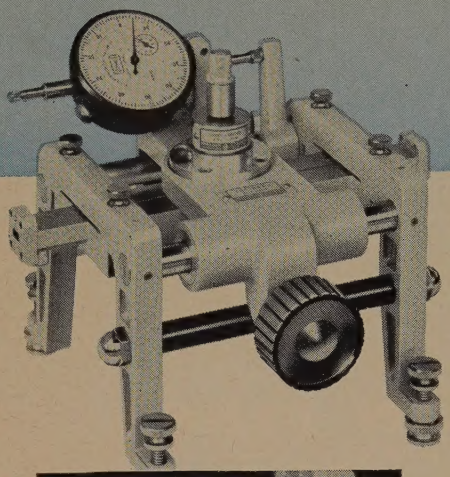

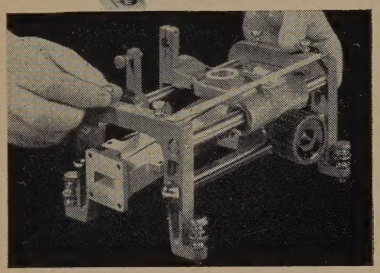

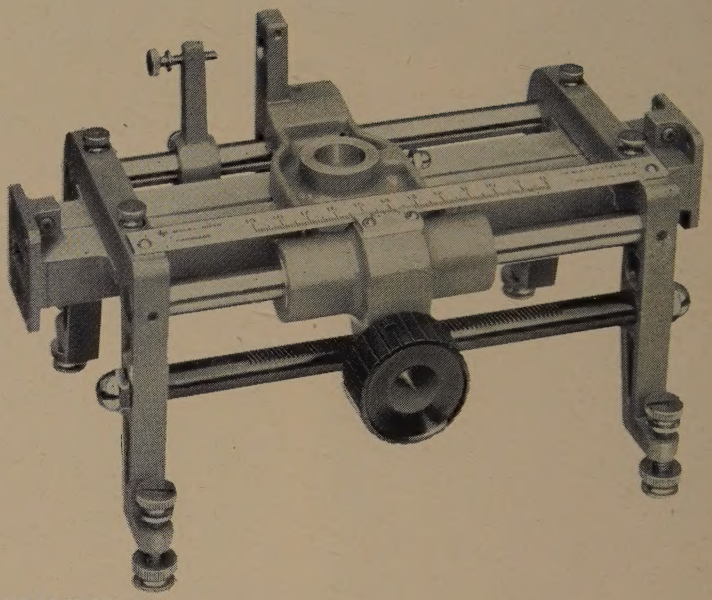

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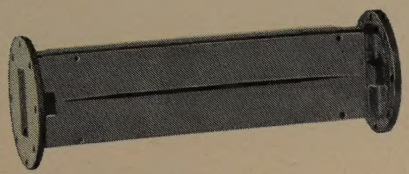
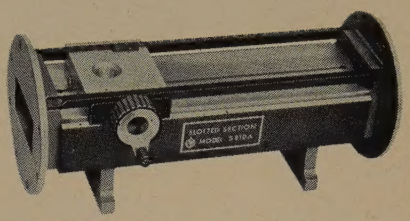


810B Waveguide Slotted Sections— 3.95 to 18.0 KMC.

These accurately machined sections of waveguide have a small, tapered, longitudinal slot, and fit the 809B Universal Probe Carriage in a precisely indexed position. A traveling probe mounted on the carriage samples the electric field along the slot, and permits precise plotting of variations. Slot reflection is less than 1.01 SWR. For prices, list of 810B waveguides available, see Table 1 below.



S810A Waveguide Slotted Section— 2.6 to 3.95 KMC.

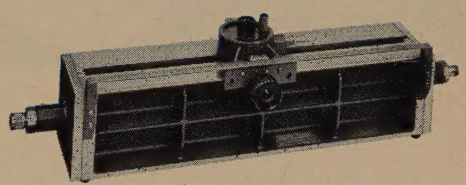
This instrument is a conventional slotted waveguide complete with a probe carriage mounted directly on the section. It is available in the S-band only and will operate with 442B or 444A probes. SWR less than 1.01. $450.00.

815B Waveguide Slotted Sections— 18.0 to 40.0 KMC.

Available in K and R band sizes, these waveguide slotted sections are similar to 810B sections and, like 810B units, are accurately machined from precision castings to insure a uniform cross-section. Prices and details below.

Table 1—810B/815B Slotted Sections.

Model	Frequency Range KMC	Fits Waveguide Size (in.)	Overall Length (in.)	Price
G810B	3.95 - 5.85	2 x 1	10¼	$110.00
J810B	5.20 - 8.20	1½ x ¾	10¼	110.00
H810B	7.05 - 10.0	1¼ x ⅝	10¼	110.00
X810B	8.20 - 12.4	1 x ½	10¼	90.00
P810B	12.4 - 18.0	.702 x .391	10¼	110.00
K815B	18.0 - 26.5	.500 x .250	4½	265.00
R815B	26.5 - 40.0	.360 x .220	4½	265.00



805A/805B Coaxial Slotted Lines— 500 MC to 4 KMC.

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THE NOISE FIGURE MUDDLE

SEYMOUR B. COHN
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NOISE FIGURE OFFERS more than its share of puzzles and paradoxes to confuse and amuse the microwave gineer. Until recently, I was vaguely familiar with the se-figure concept, and thought I understood it sufficiently ll for any purpose. However, an interest in parametric plifiers at last forced me to make use of noise-figure ory, and thus revealed my profound ignorance. Because strange facts I encountered may be interesting to those you who are not experts, I have chosen noise figure as subject of this technical editorial.

The noise figure, F, of a 2-port network has been defined Friis as follows:

$$F = \frac{N_{out}}{N_{in}} \cdot \frac{S_{in}}{S_{out}}, \qquad (1)$$

ere N_{in} is the available input thermal-noise power from generator resistance in the bandwidth of the network, ut is the available ouput noise power, S_{in} is the available ut signal power from the generator, and S_{out} is the ilable output signal power. S_{out}/S_{in} may be defined as gain G of the network. N_{in} is equal to kTB, where k Boltzmann's constant, T is the temperature of the gen- tor resistor (usually assumed 290°K, giving $kT = 10)^{-21}$ watts per cycle bandwidth) and B is the effec- e bandwidth of the network in cycles per second.

Equation (1) makes noise figure seem a simple, straight- ward quantity to measure. One measurement method, *signal-generator* method, uses a signal generator with ibrated power to provide an input signal that just doubles output power, so that $S_{out} = N_{out}$. Then by Equation), $F = S_{in}/N_{in} = S_{in}/4(10)^{-21}B$, and thus F is de- mined from the values of S_{in} and B.

A second measurement method, the *noise-source* method, s a wide-band noise source as the input signal. Let F_s the ratio of noise-source output per cycle bandwidth to . Then S_{in} is the excess input noise, $F_s kTB - N_{in}$, ere $N_{in} = kTB$. If we define N_1 to be the output noise h the noise source replaced by an equivalent impedance temperature T = 290°K, and N_2 to be the output noise h the noise source connected to the input, then ut $= N_1$ and $S_{out} = N_2 - N_1$. Therefore Equation (1) comes

$$F = \frac{F_s - 1}{\frac{N_2}{N_1} - 1} \qquad (2)$$

Now comes the first surprise for the unprepared. Noise- ure values measured by the above two methods may not ee, even when all causes of inaccuracy are eliminated. e discrepancy may in fact be as large as 2 to 1 (or 3 db) practical cases. Unless all users of noise-figure data real- this, misunderstanding may arise that can lead to serious ign error in system sensitivity.

The discrepancy in the two measurement methods ap- rs in nonlinear networks such as mixers or parametric plifiers. For example, an ordinary radar receiver with bandwidth B is receptive to input signals at the image quency as well as at the signal frequency, and hence es in noise from the wide-band noise source over a

bandwidth 2B. If a filter is placed at the input to reject the image response, noise will enter only in the signal band, and the two methods will agree, since $N_1 = N_{out} = F_{sg}kTBG$ and $N_2 = N_1 + (F_s - 1)\,kTBG$, where F_{sg} is the noise figure by the signal-generator method. When substituted in Equation (2), these yield

$$F_{ns} = F_{sg}$$

where F_{ns} is the noise figure measured by the wide-band noise-source method. But when a filter is not used at the input,

$$N_1 = F_{sg}kTBG$$

as before, and if the mixer is equally receptive to the signal and image bands

$$N_2 = N_1 + (F_s - 1)kT(2B)G.$$

Hence,

$$F_{ns} = \frac{F_{sg}}{2},$$

which shows an exact 2:1 difference, or 3 db.

Now we can see how a person using the noise-source method may undergo a confusing experience. Suppose he tries to improve his microwave receiver by adding an image-rejecting filter. This will usually decrease F_{sg} by an expected slight amount, while F_{ns} will *increase* by almost 3 db! This increase rather than decrease in measured noise figure, when half the thermal noise entering the mixer is eliminated by the filter, can certainly startle the unwary.

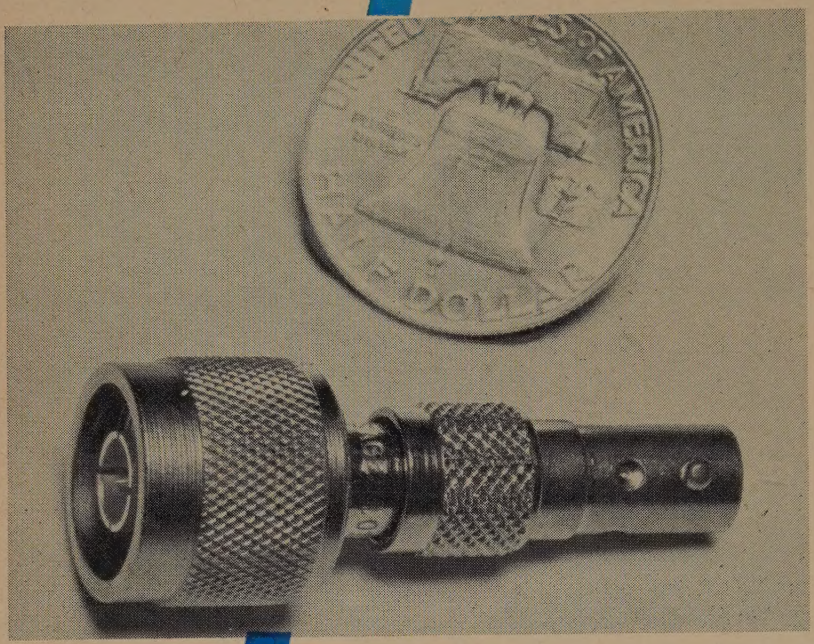
Which value of noise figure should we use? There is considerable controversy on this subject.* In the opinion

Editor's Note: Inadvertently four lines were omitted from the second page of this article. They should be inserted between the fifth and sixth lines at the top of the right-hand column on Page 9, following the words "Let us further assume the frequency bands at f_1 and f_2 are . . .

separated at the input and output as shown in Fig. 1. Then the input thermal noise at f_1 will appear at the output as kTBG. In addition, input thermal noise originating at f_2 will appear at the output as $kTBG \cdot (\omega_1/\omega_2)$. (The

We wish to apologize to the author for this error.

*The IRE definition of noise figure (Proc. IRE, vol. 40, p. 1684, Dec. 1952) agrees with Friis' definition (Equation 1), but is more specific about mixed frequencies. Strict adherence to the IRE definition would yield noise-figure measurements in agreement with the signal-generator method. Unfortunately the IRE definition has frequently been ignored.



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myself and many others, the value that corresponds best ith the system's intended use is the correct one. Thus, r the usual radar or microwave relay receiver, the signal-enerator value is correct, since the signal enters only one put band, and thermal noise entering the unused image nd should be considered part of the mixer noise. On the her hand, the noise-source value would be appropriate r a radio-astronomy receiver, where useful noise signal ters both bands.

Despite my criticism of the noise-source method, I do ot advise abandoning it in favor of the signal-generator ethod. The fact is, noise-figure measurement with a noise urce is simpler and more closely repeatable than with signal generator. I recommend the use of the noise-source ethod in most cases, but with the reading corrected as ecessary to correspond to the purpose of the device under st. Thus, for an ordinary radar receiver equally sensitive image and signal, the reading should be increased by db to yield the valid noise figure.

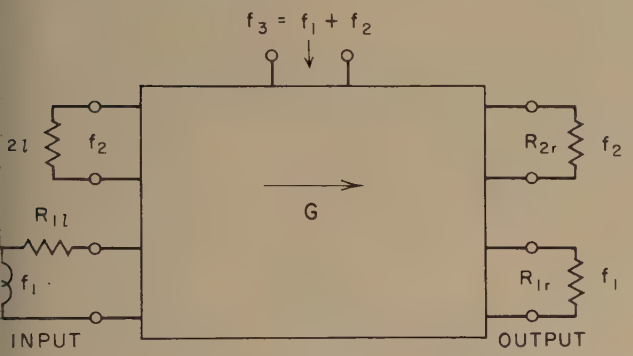

Fig. 1

Noise figure is confusing enough when applied to ordi-ary mixers, but parametric amplifiers present more sur-rises. The basic parametric amplifier with signal fre-uency f_1, idle frequency f_2, and pump frequency $f_3 = f_1 + f_2$ offers the same problems as a mixer, with new ones dded to expand the confusion. For example, the single-ode negative-resistance parametric amplifier is likely to ave a bandwidth smaller than that of the receiver follow-ng it, making corrections of the measured data necessary. nother difficulty is that the amplifier will be regenerative most to the point of oscillation so that, unless a circulator used, small changes in generator or load impedance will use large changes in gain. This can lead to large errors hen the noise source is removed, unless great care is ken to replace the noise source by an identical impedance ooking back from the input port. Also, the output power om a negative-resistance source can no longer be regarded *available* output power, and therefore S_{out} and N_{out} are st re-defined as output powers into a characteristic-im-edance load. Without a circulator, thermal noise from e load resistor will enter the output port of the amplifier, nd will return to the load greatly amplified. This compo-ent of noise can be a large part of the total output noise, nd should not be neglected in theoretical calculations of $_{out}$. In this limited space I cannot elaborate on these oints, but it should be clear that great care must be ken if accurate data is to be obtained.

To simplify the discussion let us assume a unidirectional traveling-wave parametric amplifier with input and output impedances matched to the transmission line, and with no internal losses that could produce thermal noise. Let us further assume that the frequency bands at f_1 and f_2 are ω_1/ω_2 factor arises from the Manley-Rowe energy relation for non-linear-reactance mixers.) Hence the noise figure appropriate to the signal-generator method is $F_{sg} = 1 + \omega_1/\omega_2$. By the noise-source method, $N_1 = kTBG \cdot (1 + \omega_1/\omega_2)$ and $N_2 = F_s kTBG(1 + \omega_1/\omega_2)$, giving $F_{ns} = 1$. As mentioned above, it is the F_{sg} value that corresponds to performance in most applications.

It may occur to you as it did to me that F_{sg} might be reduced to unity by replacing R_{2l} on the left by a reactance, because a reactance does not produce thermal noise. However, this measure will not help, since R_{2r} on the right will emit thermal noise at f_2 that will travel back through the amplifier with essentially no gain or loss, and then will reflect back into the amplifier and be converted to f_1 at the output, yielding the same noise figure $F_{sg} = 1 + \omega_1/\omega_2$ as before. If both R_2 and R_{2r} could be replaced by reactances, no thermal noise would originate at f_2. But unfortunately no gain would then be possible, since the power generated by the diodes at f_2 must be dissipated if gain is to be achieved. There are only two ways to reduce F_{sg}; one is to make ω_1/ω_2 small; the other is to cool R_2 to temperature T′, in which case $F_{sg} = 1 + \frac{\omega}{\omega_2} \cdot \frac{T'}{290^\circ}$

The degenerate-frequency case of $f_1 = f_2 = f_3/2$ is of special interest. Consider the parametric amplifier of Fig.

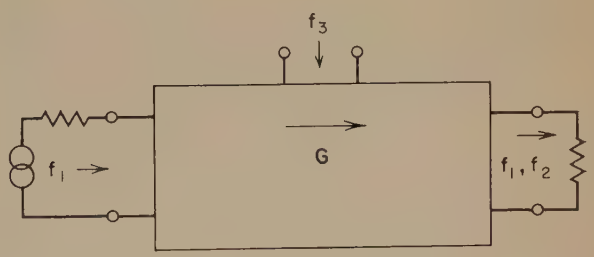

Fig. 2

2, where a signal f_1 slightly lower than $f_3/2$ is introduced at the left, and both f_1 and f_2 emerge from the right. If a narrow-band filter tuned to f_1 is connected to the output, the device will operate as an amplifier with power gain G. If f_1 and f_2 are brought close enough together so that the output voltages at both f_1 and f_2 pass through the filter, the voltages will beat at a rate that becomes slower as f_1 approaches f_2. The voltage at the peaks will be twice that for f_1 alone, and hence the power gain at the peaks will be 4G. If f_1 and f_2 are made suddenly equal just when the output is at a peak, the gain will remain constant at 4G. Let us now consider the noise output when the output filter restricts the amplifier bandwidth to B centered at $f_3/2$. The input noise in the half-bandwidth below $f_3/2$ will produce noise output $kT(B/2)G$ in the half-bandwidth below $f_3/2$ and $kT(B/2)G$ in the half-bandwidth above $f_3/2$, a total of kTBG. Similarly, the input noise in the half-bandwidth above $f_3/2$ will also produce noise output kTBG. Therefore, total N_{out} is 2kTBG, while total N_{in} is kTB. When these values and $S_{out} = 4GS_{in}$ are substituted in Equation

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(*Continued from page 9*)

), the following noise figure results:

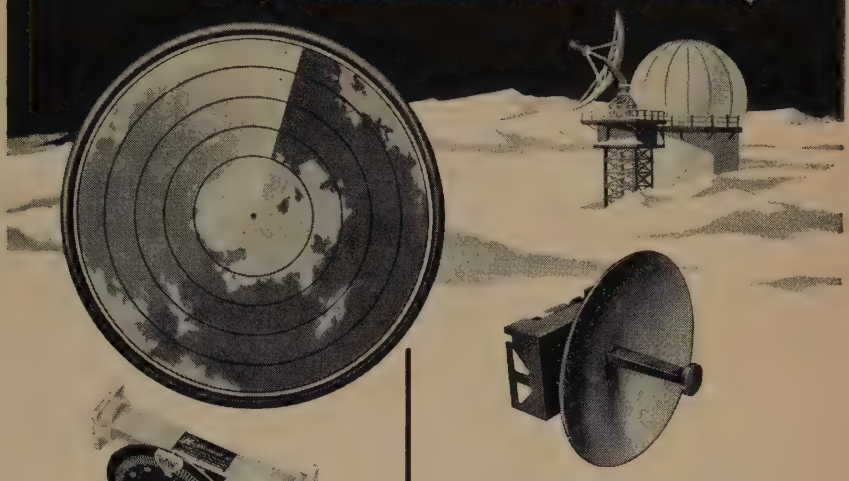
$$F_{sg} = 1/2.$$

other words, the parametric ampli-
r has improved the signal-to-noise
tio of the original input energy by
db! Experts among us will not be
rprised by this result, but most of us
ill certainly suspect a flaw in the an-
ysis. For surely the laws of thermo-
namics are violated! But this is not
. There are no basic flaws and no
w is disobeyed. The following ex-
anation should make this clear.

The parametric amplifier in the de-
nerate mode operates not as an ordi-
ry amplifier, but as a phase-sensitive
nplifier. Maximum gain occurs for
e component of input signal in the
oper phase with respect to the phase
the pump signal, while the quadra-
re component of input signal has
sentially zero gain. Because the in-
t noise is random, half the noise
wer components are improperly
ased for amplification, and therefore
ly half the noise power is amplified.
e have assumed, however, that the
put signal is phased for maximum
nplification. Hence the signal-to-
ise ratio is improved by 3 db, and
is in truth equal to 1/2, or —3 db.
will now be obvious that this noise-
duction effect does not require a
rametric amplifier, but may be
ieved with any phase-sensitive
twork. Of course, to be able
obtain this signal-to-noise-ratio
provement in a practical system, it
st be possible to lock the signal
ase with respect to the pump phase.
so, the effect of a detector on the
plified signal and noise should be
nsidered carefully, since noise figure
defined in terms of signal and noise
wers before detection, whereas noise
ctuations in the detected modulation
usually of more direct concern to
tem performance. A properly phased
ase-sensitive amplifier will reduce
ise fluctuations in the output signal
a subsequent AM detector only
en S/N is near unity, and will give
stantially no improvement when
N greatly exceeds unity.

I did not mean this discussion to be
complete survey of noise figure.
ther, I have tried to show some of
traps and sources of error in
concept. My editorial will have
ieved its purpose if it guides the
der around these pitfalls, and if it
courages him to seek for himself
re detailed knowledge on the sub-
t.

precision assures reliability



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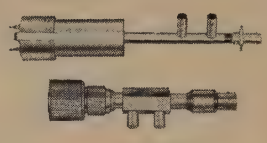

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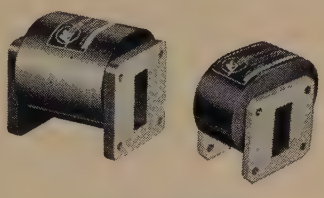

FERRITE ISOLATORS

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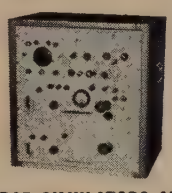

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CIRCLE READER SERVICE CARD 7

A few years ago there was some interest expressed in simplifying the English language. To the best of our recollection it involved the adoption of a somewhat limited vocabulary described as Basic English.

We mention it here to point out one of the great obstacles in our own, as well as other, industries. The obstacle is the difficulty of communication by means of words, either spoken or written.

With the increased pace of our living today we have a tendency to do things in a hurry. There is never enough time to meditate, study, investigate. Words fly at us and if we do not recognize them immediately, there is often a tendency to wait until a more convenient time to find a good definition. More often than not we forget or are too lazy, to look up the definition. The net result is a small area of no understanding.

As new ideas, techniques, and devices are added to the industry they are invariably coupled with new words. The words are our keys of communication. If we do not understand their meaning the communication breaks down completely and the small area of no understanding becomes a large area of complete mystery.

Actually, there are two sources of difficulty in this communication problem. One is the transmitter or word coiner who loves to parade his vocabulary whenever possible. The other is the receiver. Be he listener or reader, either too proud to ask or too lazy to search. They are both guilty of this breakdown of communication and they are us or at least most of us.

We could probably reason that Microwaves is a science and consequently we should simplify the language to help improve communication. On the other hand many people will say it is still an art and we should give vent to our artistic talent.

Reading certain technical papers and hearing certain talks, we are reminded of that old saw, which slightly modified, relates to knowing more and more about less and less.

The interesting point is that here we are involved in the field of communication, working to improve performance while simplifying design, yet at the same time we are allowing our own personal communication to deteriorate.

The real question is not whether we should resort to basic English but rather, if we do, how many experts will be left.

We pause a moment to acknowledge the big electronic event of the year, the IRE exhibit in New York, March 23-26. "the microwave journal" congratulates the IRE on the success of this program and wishes are extended for the most successful event to date.

We look forward to visiting with friends, old and new, who have made this first year of our operation a memorable one. This is also an ideal opportunity for us to contact advertisers and readers and gather ideas for a more useful publication to the microwave industry.

May we, at this time, beg your indulgence for the delays encountered in honoring your requests for the "journal." Each issue has deluged us with a heavy volume of new subscriptions, which are processed as rapidly as possible. We are flattered by the compliment but are concerned about the delays in getting the magazine to you.

In our next issue we will feature a paper on Gaseous Scanners by Jones and Lowrey of Melpar, a paper on a Klystron Amplifier by Rockwell of Varian Associates, and one on Noise Figure Measurements by Saul and Luloff of Polarad. The editorial will be by Marshall Pease, the Company Profile will be Part II of Raytheon, and Paul Garrison of I-T-E, Special Products Division, will supply the Business Editorial.

Theodore S. Saad

SYMPOSIUM ON RADAR RETURN

A symposium will be held at t University of New Mexico, spo sored by the Naval Ordnance T Station, China Lake, California, May 11-12. Papers dealing with ra return from ground and water targ will be presented. (Subjects havi application to radar altimeters are receive special emphasis.)

The sessions for May 11 will co tain papers that are unclassified a are open to all interested in the fi of radar return. Classified sessions quiring a clearance of Secret will held on May 12. The meetings w be held in Johnson Gymnasium. Ple make clearance arrangements with, a send classified abstracts and papers Mr. H. L. Walker, Director of R search, Box 4036, Albuquerque, N Mexico.

Submission of Papers. Authors a invited to submit, *on or before Ma 1,* titles and a 100-150 word abstr of paper for presentation at the sy posium. Please prepare your paper *duplicate,* and if *unclassified,* mail to: Mr. F. J. Janza, Symposium C ordinator, E.E. Dept., Univ. of N Mexico, Albuquerque, New Mexi Otherwise, mail classified papers to M H. L. Walker. Unless otherwise s cified by the authors, all papers p sented or received, and considered p tinent to the problem area, will be pu lished in an unclassified, or classifi Radar Return Symposium Rep These reports will be available to participants immediately after pub cation. Papers must be received later than May 12. Also include in t abstract your affiliation and address.

Topic areas that are of interest this symposium are as follows:

1. Theoretical Analysis of Ra Returns
2. Measurement Methods
3. Results of Measurements
4. Data Reduction
5. Applications to Systems D sign and Analysis

There will be panel discussio which will be announced at a la date.

Please address any questions in gard to the symposium, transpo tion, hotel accommodations, etc. to F. J. Janza.

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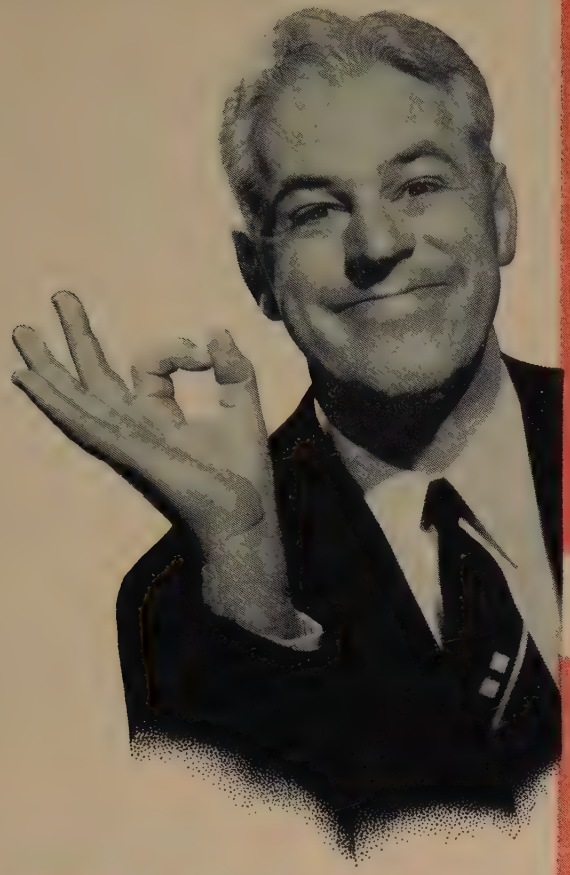

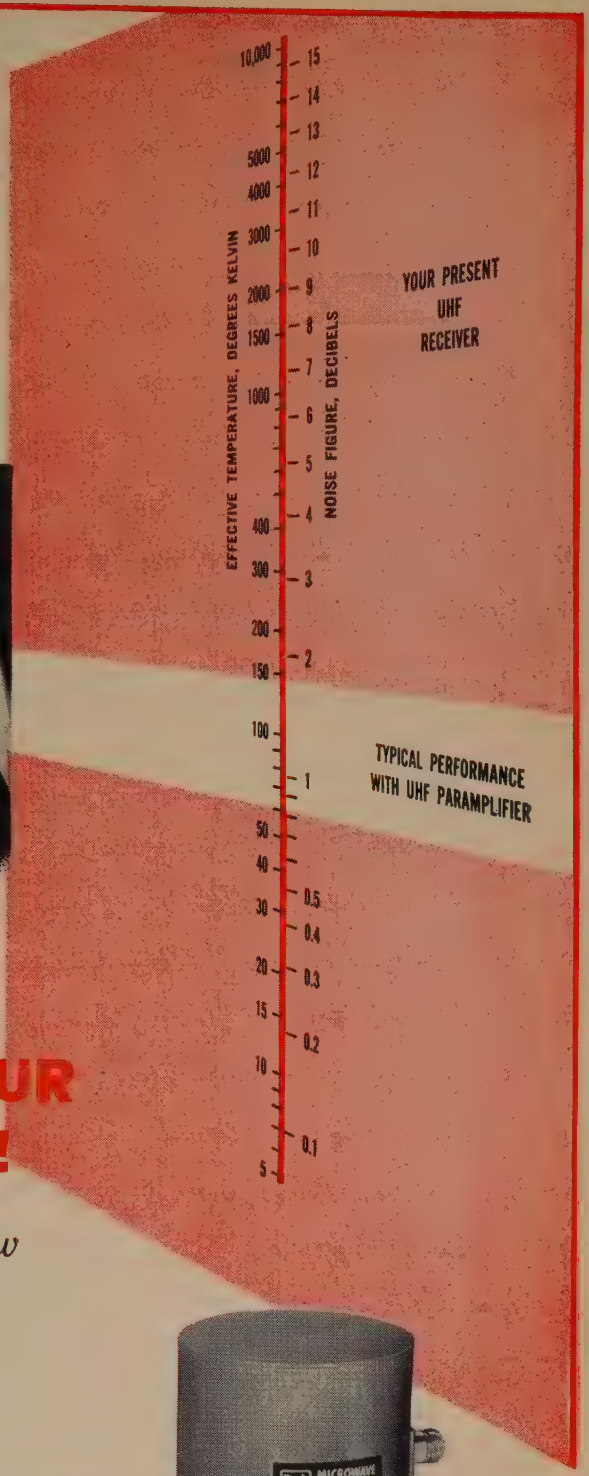

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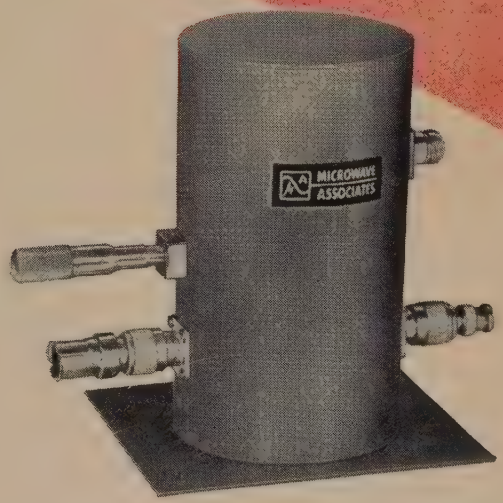

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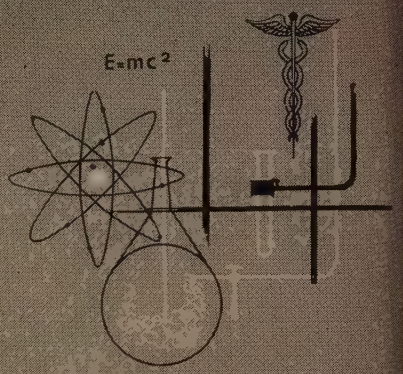

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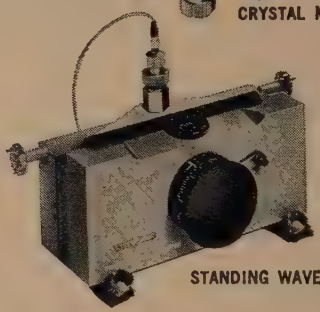
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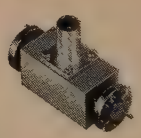
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1N26
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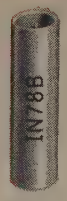

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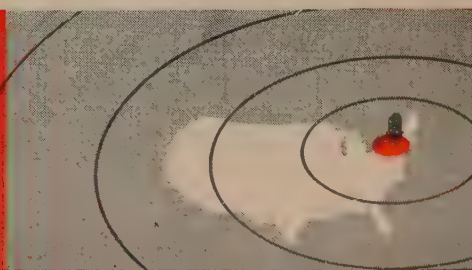

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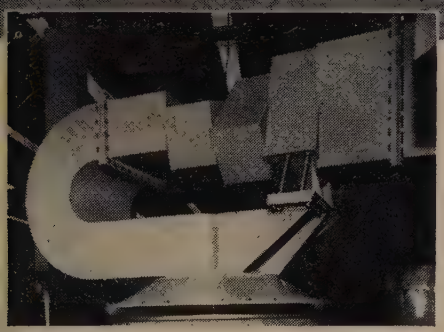
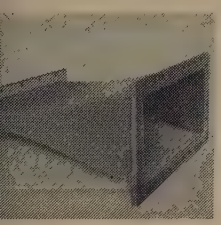
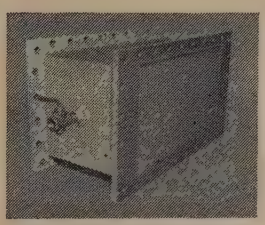
A complete large waveguide service. These units reflect I-T-E's design and production capabilities with large waveguide. Noncontacting short circuit section shown is available with servo-controlled motor drive. For proper electrical continuity, all waveguide flanges are held to 0.001 in. flatness (total indication) . . . are perpendicular within 0.030 (for two flanges, total indication). Available in sizes WR770 through WR2300.



Rotary joint and step twist. High-power rotary joint designed for low VSWR. Binomial stepped 90° twist has 1.02:1 VSWR over wide band.



veguide transformer tures low VSWR, h power, economy.



Gas barrier utilizes Rexolite window for maximum RF transmission.

I-T-E is staffed and equipped to meet your requirements for large waveguide used in multimegawatt radar and scatter communications systems. For conventional needs, I-T-E manufactures an extensive line of standard configurations. And where special problems exist, depend on I-T-E waveguide engineers to originate special designs exactly suited to your wants and at reasonable cost.

Productionwise, I-T-E can provide faster deliveries, thanks to its fully equipped waveguide shop. Custom-designed tools and fixtures assure both flaw-free fabrication and production-line efficiency. Every step—from the initial sheet metal work to final finishing—is performed under one roof . . . under one responsibility. You benefit from lower VSWR, plus maximum strength with lightness and economy.

Let I-T-E's broad design experience and unique production facilities work to solve your waveguide problems. Address your inquiries to I-T-E's Special Products Division. And ask for your copy of free-space vs. guide wave lengths conversion tables for large waveguide.

I-T-E CIRCUIT BREAKER COMPANY
Special Products Division • 601 E. Erie Avenue • Philadelphia 34, Pa.

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LEADERS IN THE FIELD

OF MICROWAVE FREQUENCY

MEASUREMENT AND CONTROL

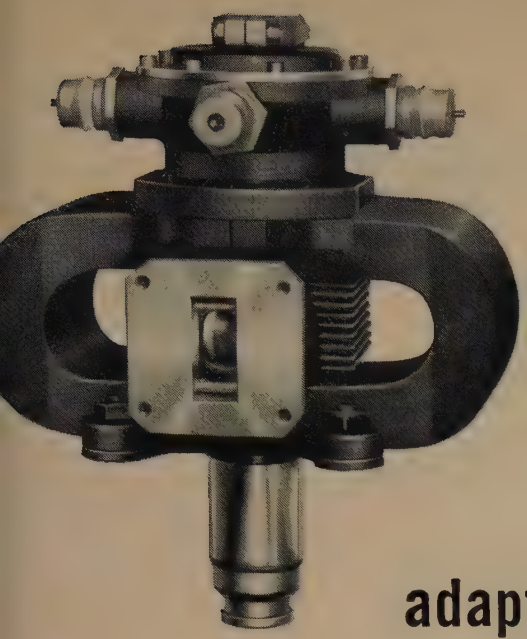
Leadership is no accident. And here at Frequency Standards t
leadership we enjoy in our field is the product of many things.
is the result of 15 years of excellence in precision manufacturin

Assuredly, it is also the result of eight years of intense design a
development work in the field of microwave frequency measu
ment and control. You will find evidence of our leadership in t
important developments we have made for the Government's ov
all defense program. And in the fact that ours is the first Compa
able to produce standard lines of Microwave Frequency measuri
and controlling devices, as well as specific design work for indust

Send for details on what has been described as the most advanc
engineering staff in this field—and literature on our standard lin
and design facilities. Address: Frequency Standards, Box 504
Asbury Park, N. J. PRospect 4-0500. Or your nearest represent
tive in all principal cities.

FREQUENCY STANDARDS

HARVARD A DIVISION OF INVESTORS, INC.



FASTEST TUNING PULSE MAGNETRON TUNES HYDRAULICALLY

adapts to current systems

his is the first public announcement of the st hydraulically-tuned pulse magnetron. It rmits a powerful new capability in anti- mming pulse-to-pulse frequency diversity eration.

Designated L-3211 and equipped with an draulic tuning actuator we developed, *this is e fastest tuning, medium power magnetron production today.*

The L-3211 is designed for X-band operation th electrical characteristics similar to those our standard field-proved 6543 magnetron. ne principles of its design make it adaptable other power levels and frequency bands.

Tubes of this family greatly enhance system tuning capability, approaching that of voltage-tuned tubes, with much greater efficiency and less system complexity. The L-3211 affords a means of upgrading both new and existing radar systems in operational effectiveness. (We also can provide information on a "need-to-know" basis on classified tubes that have even greater capabilities than the L-3211.)

In constructing the L-3211 we use certain techniques proprietary with us . . . techniques which guarantee a long operating life and a long shelf life. Ageing-in prior to full-power operation is unnecessary.

It is another one of a large number of microwave tubes used in radar and countermeasures built to specifications established by Litton Industries . . . specifications which have become recognized as standards by the military services.

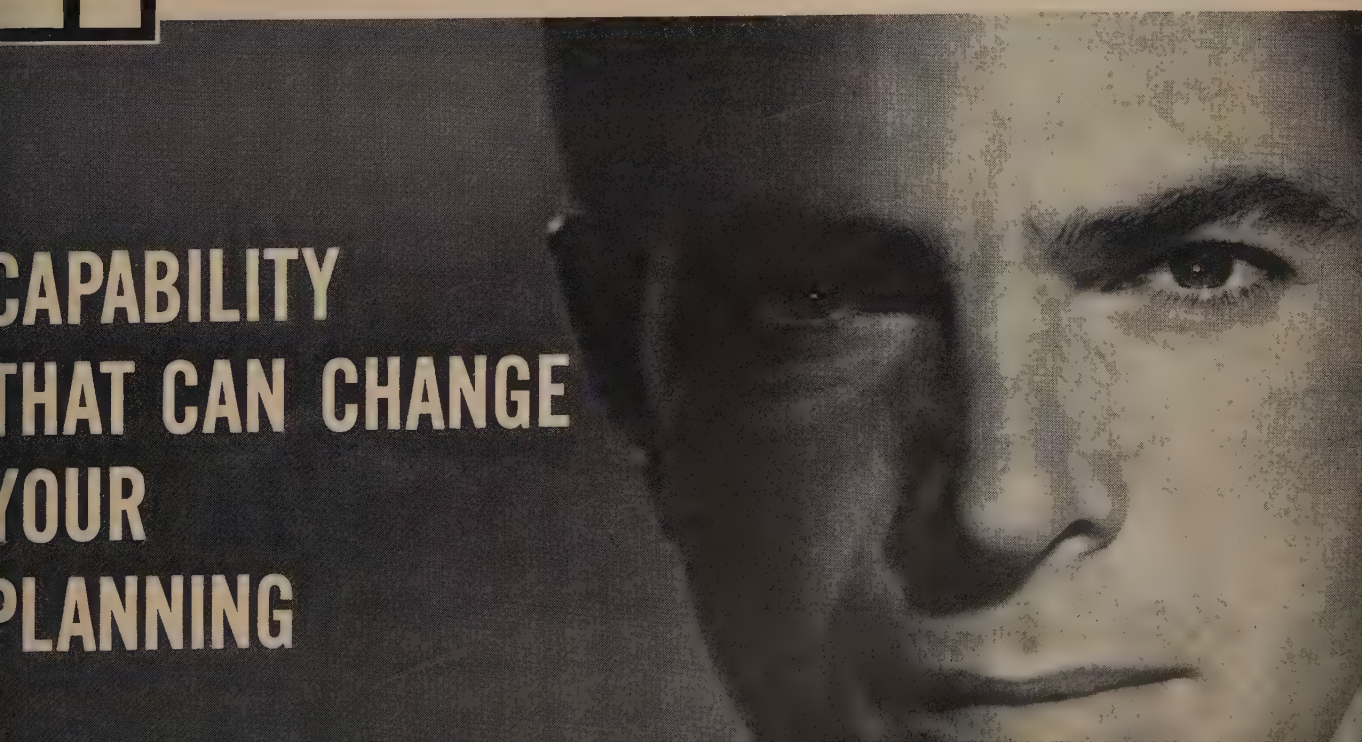
Our Applications Engineering Lab is well equipped* to analyze your problem. It has been remarkably successful in finding fast and accurate solutions to difficult system problems. Let it solve yours. We'll be glad to answer your specific inquiries, or to send you a copy of our catalog. Litton Industries Electron Tube Division, Office M3, 960 Industrial Road, San Carlos, California.

*Incidentally, so is our Personnel Department.

VISIT OUR BOOTHS AT THE IRE SHOW CIRCLE READER SERVICE CARD 14

LITTON INDUSTRIES Electron Tube Division

MAGNETRONS • GAS DISCHARGE TUBES • CARCINOTRONS • TRAVELING WAVE TUBES
KLYSTRONS • BACKWARD WAVE OSCILLATORS • NOISE SOURCES • DISPLAY TUBES



AN IMPORTANT NEW PRODUCT ANNOUNCEMENT FROM HUGHES!

PARAMETRIC AMPLIFIER DIODES

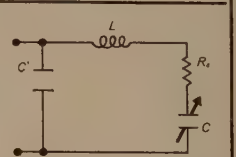
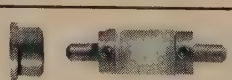
FOR LOW-NOISE MICROWAVE AMPLIFIERS

Now Hughes Products brings you high performance parametric amplifier diodes at a price in the same range as good microwave mixer crystals. These Hughes diodes have been designed to solve your problems associated with low-noise parametric amplifiers, modulators, frequency converters, harmonic generators, electronic tuners, switches, etc., at microwave as well as at lower frequencies.

Used in a 3000 Mc high gain parametric amplifier with both signal and idler channels as inputs, these diodes have produced at room temperature in the laboratory a noise temperature of 100°K above absolute zero. Noise temperatures of 50°K above absolute zero were obtained when diode was cooled by liquid nitrogen.

The Hughes Parametric Amplifier Diodes are available in two rugged, hermetically sealed versions. One has a miniaturized glass package (type HPA 2800); the other has been adapted to a conventional microwave package (type HPA 2810). Both are hermetically sealed in glass and have the same cutoff frequency.

TECHNICAL SPECIFICATIONS AND DATA:

Package (actual size)	C′	C @ zero bias (nominal)	cutoff frequency* (nominal)	L (nominal)	V_S** Min.	V_S** Nom.	Equivalent Circuit
HPA 2800	0.1 μμf	2.5 μμf	70KMC	4 mμh @ 1KMC	5V	7V	
HPA 2810 	0.2 μμf						

*At breakdown voltage **Breakdown voltage (10 μA point)

Address inquiries to:
Hughes Products, Semiconductor Marketing Dept., P. O. Box 278, Newport Beach, California.

CAPACITANCE vs. BIAS VOLTAGE	Reverse Bias Voltage	Capacitance C
	0 V	2.5 μμf
	3 V	0.76 μμf
	7 V	0.60 μμf

Creating a new world with ELECTRONICS

HUGHES PRODUCTS

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SEMICONDUCTOR DEVICES • STORAGE AND MICROWAVE TUBES • CRYSTAL FILTERS • OSCILLOSCOPES • RELAYS • SWITCHES • INDUSTRIAL CONTROL SYSTEMS

CIRCLE READER SERVICE CARD 15

MICROWAVE EQUIPMENT
STEPCHILD OF THE SYSTEM

J. KELSEY BURR, 3rd., VICE PRESIDENT MARKETING
FREQUENCY STANDARDS
INC.

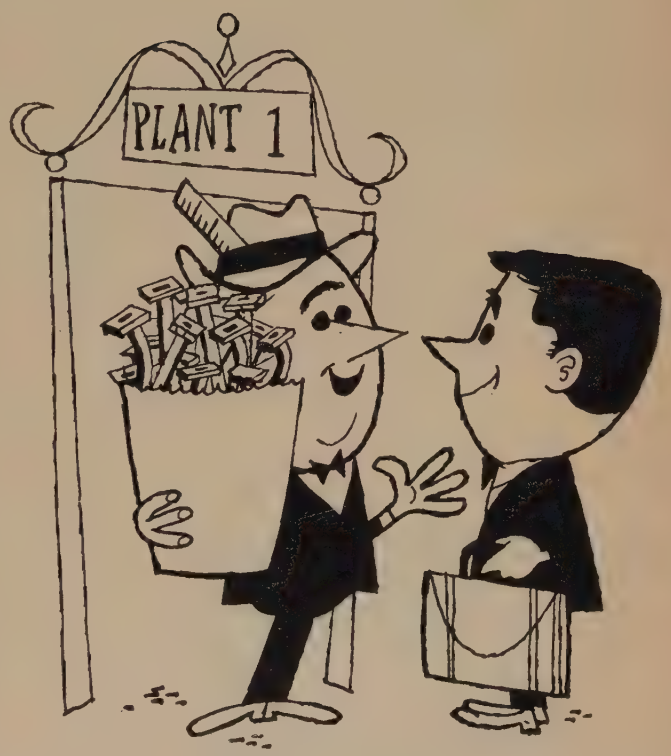
Many people who read this editorial may question the rcefulness of its title. But if we actually stop and lect about the problems and ramifications of selling mponents to the systems engineer and/or manufac-er, we may discover several enlightening points.

The microwave industry is a young industry and the oblems involved in selling components are of sufficient gnitude to warrant much discussion, possibly even f-criticism. This is not to imply that the systems engi-er himself is blameless and does not contribute to the erall problem. However, if any corrective steps are to taken, it is the responsibility of the industry faced with h problems, to solve rather than shift blame to the yer — which has been done all too often, in my ex-ience.

Take the case of X Company whose talents and prom- are recognized. For years, Clyde Smedley, President X Microwave Company, has dreamed of developing waveguide bend with a VSWR of 1.0. He finally ar-es at something close to his dream and forms his mpany. With the money with which he was about to his wife a fur coat, he opens and employs Sam Sharp act as Sales Manager. Of course, Sam has an enviable ord in sales, having formerly been associated with the psy Turvey Lollipop Company. And, "away we go." Mr. Sharp takes the bend which, because the money is ning short, is not quite perfected and goes to the B.C. Corporation, the largest buyer of waveguide ds. Here he is courteously introduced to the systems gineer who needs a good bend. Sam shows this wave-de bend to the engineer and describes from a piece paper the specifications that Mr. Smedley hopes to ieve.

From the specifications that Sam has set forth, the gineer is no doubt impressed and since he is working Project Q, which is an ultra, ultra secret crash pro-m, he wastes no time buying substantial quantities of se optimum devices — with one reservation, he won-s where Sam got his education in microwave equip-nt.

am hurries back to Clyde and unfolds this illustrious



order that he has taken for delivery next week. Now creeps in the age old philosophy of "promise them anything, but get the order." Six months later A.B.C. Corporation is still without their bends, Sam and Clyde are still trying to perfect the optimum, and our illustrious systems engineer has been fired for failure to complete his program.

While the above description of this farce is both facetious and ludicrous, certain elements within it are not as far from reality as they may seem. It is time we opened our eyes to some realistic situations in an attempt to take corrective actions, as a growing industry should.

Let us, in our industry, attempt to set standards which are ethical and accurate. When we talk about insertion loss, let's specify the tolerances at which this loss can

be measured. When we talk about frequency accuracy, let's know what we mean by frequency accuracy. And, let's not forget the environmental conditions. I am sure that many of us sometimes have had the opinion that the environmental specifications laid down are unnecessarily extreme. If we feel this to be true, let's stand on our feet, as an Industry, and say that they are unrealistic rather than accept them as such and say, "Oh well, they won't be able to test them anyhow."

And now about specifications? I am sure that we all could re-write our specifications' list and catalogs with a critical eye towards supplying more complete and detailed information for the engineer.

Another complaint! Let's not shoot for the moon tomorrow. Let's accept and quote the specifications that are realistic. Let's build equipment that is repeatable — not quote specifications as a result of endless tinkering on the test bench.

Then there's marketing! I think that it is high time we attempted to gain respect for our sales engineers. Let's not have the customer consider them "order takers." There is only one way to solve this problem, and that is to get engineers who know and understand the product they sell.

And then for my biggest gripe of all! Let's quote the customer in terms of realistic deliveries. Many times because a microwave company will imply that much of the equipment is standard — when in actuality it is not even a bread-board design in many occasions — the customer logically will think that delivery should be next week. So let us be sure we advertise as standard equipment only what is standard. And when the customer requires development or modifications of standards, let's quote him a delivery that is realistic and not merely a date that is compatible with what the customer desires.

The only way that the Microwave Industry can be fully respected as an Industry, is through self-scrutiny and self-policing of all the companies that form its parts. In this light, I think a partial solution is in the formation of an association composed of those companies directly engaged in microwave equipment manufacture. By this suggestion I do not mean to imply that those associations such as the Institute of Radio Engineers and Electronic Industry do not serve a good purpose. However, since they cover the full, broad gamut of electronics, many of the companies within these organizations do not have the peculiar and particular problems of our Industry. This type of association for the Microwave Industry would take away in no possible manner from the competitive spirit of its members. However, it would add to the prestige of the Microwave Industry in such a fashion that we should all be proud to be associated with Microwave Equipment manufacturing and marketing.

J. KELSEY BURR, 3rd was born in East Orange, New Jersey on March 21, 1930.

After a brief tour with the U.S. Marine Corps from 1948 through '49, he was employed by Manufacturers Thread Grinding in Production. He re-entered the Marine Corps in 1950 to 1952.

At the end of 1952, he returned to participate in the formation of Frequency Standards where, at the time of their merger with National Electric Products Corp. of Pittsburgh, he served in the capacity of assistant to the President. Under the merged organization, he was appointed Vice-President of Marketing.

Mr. Burr has attended Rutgers University, taking various courses in business management.

He is a member of the American Management Association and American Ordnance Association.

Mr. Burr is married and the father of three children. His vocation, avocation, and hobby are Frequency Standards, consequently his wife and children share none of his interests.

Creative Microwave Technology

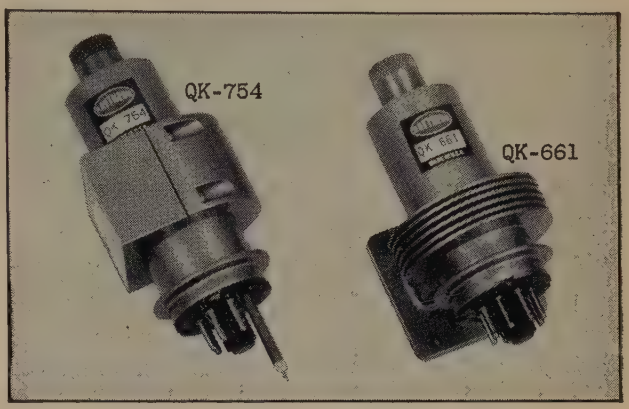
Published by MICROWAVE AND POWER TUBE DIVISION, RAYTHEON MANUFACTURING COMPANY, WALTHAM 54, MASS., Vol. 1, No. 2

NEW ONE-WATT COMMUNICATION KLYSTRONS COVER GOVERNMENT AND COMMON CARRIER BANDS

signed primarily for use in microwave lay links, the QK-661 and the QK-754, e-watt transmitter klystrons, operate frequencies of 7,125 to 8,500 Mc and 925 to 6,425 Mc, respectively. The QK-1 is the first tube of its kind to cover e entire government band. The QK-754 is e first of a planned series of tubes to ver the entire communications band.

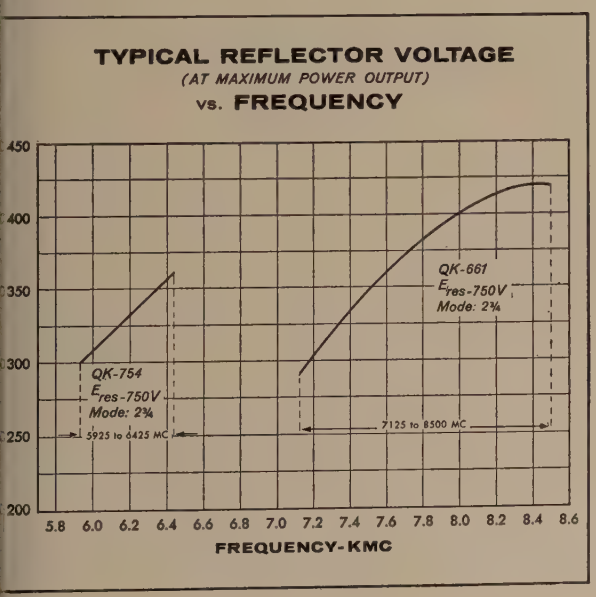
th are mechanically tuned, integral-vity, long-life, reflex-type tubes. The -754 uses a coaxial output; the QK-661, aveguide output.

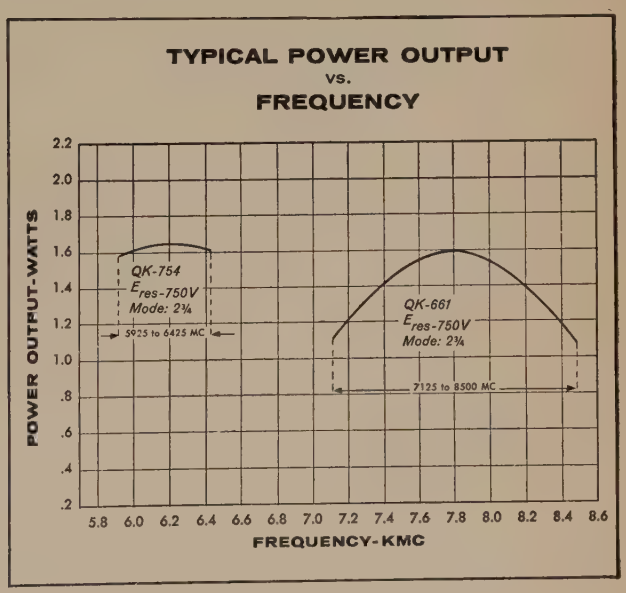
insure efficient operation the tubes e available with integral cooling fins with a heat-sink attachment suitable r connection to the chassis.



Typical operating characteristics

	QK-754	QK-661
Frequency Range	5925 to 6425 Mc	7125 to 8500 Mc
Power Output	1.5 watts	1.6 watts
Electronic Tuning (to half-power pts)	50 Mc	25 Mc
Modulation Sensitivity (10 V pk-to-pk mod volt)	1 Mc/V	600 Kc/V
Temp. Coefficient	± 0.1 Mc/°C	± 0.1 Mc/°C





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RAYTHEON

You can obtain detailed application information and special development services by contacting: Microwave and Power Tube Division, Raytheon Manufacturing Company, Waltham 54, Massachusetts

A LEADER IN CREATIVE MICROWAVE TECHNOLOGY

CIRCLE READER SERVICE CARD 16

We promise you will receive a reply within one week!

NEW OPENINGS AT HUGHES RESEARCH & DEVELOPMENT LABORATORIES

Hughes has several hundred openings for engineeers and physicists whose training and experience are applicable to the research, development, design and testing of airborne electronic equipment for use in supersonic military aircraft; in solid state physics, nuclear electronics, industrial dynamics, and related areas.

Use of the following form will, we hope, reduce to a minimum the inconvenience of submitting an employment inquiry, yet will still permit us to give you a reasonably definitive reply.

Please airmail to:
Mr. Robert A. Martin, Supervisor, Scientific Employment
Hughes Research and Development Laboratories
Culver City, California

HUGHES

*Name*_____

*Address*_____

*City*_____ *Zone*_____ *State*_____

*College*_____ *Degree*_____ *Year*_____

I am interested in one of the following types of assignment:

☐ RESEARCH ☐ PRODUCT ENGINEERING ☐ SYSTEMS ☐ OTHER:_____
☐ DEVELOPMENT ☐ TECH. ADMIN. ☐ FIELD TEST ☐ _____

I have had professional experience in the following specific areas:

☐ CIRCUIT ANALYSIS AND DESIGN ☐ STRESS ANALYSIS ☐ R-F CIRCUITS ☐ ELECTRO-MECHANICAL DESIGN
☐ DIGITAL COMPUTERS ☐ INDUSTRIAL DYNAMICS ☐ RELIABILITY ☐ OTHER:_____
☐ GUIDANCE DEVICES ☐ MATERIALS ☐ ATOMIC AND/OR SOLID STATE PHYSICS ☐ _____
☐ MICROWAVES ☐ SYSTEMS ANALYSIS ☐ INSTRUMENTATION ☐ _____

I have had a total of _____ years of experience.

We would like to paraphrase the 1959 IRE Show theme, Inspiration in Radio Electronics, by pointing out this example of Kennedy Inspiration in Reflector Engineering, a 40-foot reflector featuring quick in-the-field assembly and disassembly.

You can see this unique antenna at Booths 2532 and 2637 at the IRE Show.

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D. S. KENNEDY & CO.

COHASSET, MASS EVergreen 3-1200

Down-To-Earth SOLUTIONS *to* *Out-Of-This-World* PROBLEMS

Tracking Antennas
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Radar Antennas
"Trans-Horizon" Antennas

CIRCLE READER SERVICE CARD 17

engineers and physicists:

microwave and radar

GPL announces senior and intermediate openings for engineers and physicists to perform work in the following areas:

Design and development of systems and/or components, with some experience required in antenna and wave-guide or receiver and transmitter design and analysis. Problems are related to new techniques in terrain clearance, airborne missile guidance and Doppler. Several of these positions require supervisory potential and carry commensurate salaries.

Engineers and physicists who wish to arrange for a personal discussion of their future at GPL should call (collect) ROgers 9-5000, or submit their resumes to William S. Schell, General Precision Laboratory Inc., 63 Bedford Road, Pleasantville, N. Y. Inquiries will be held in strictest confidence and answered promptly.

GPL | A GENERAL PRECISION COMPANY

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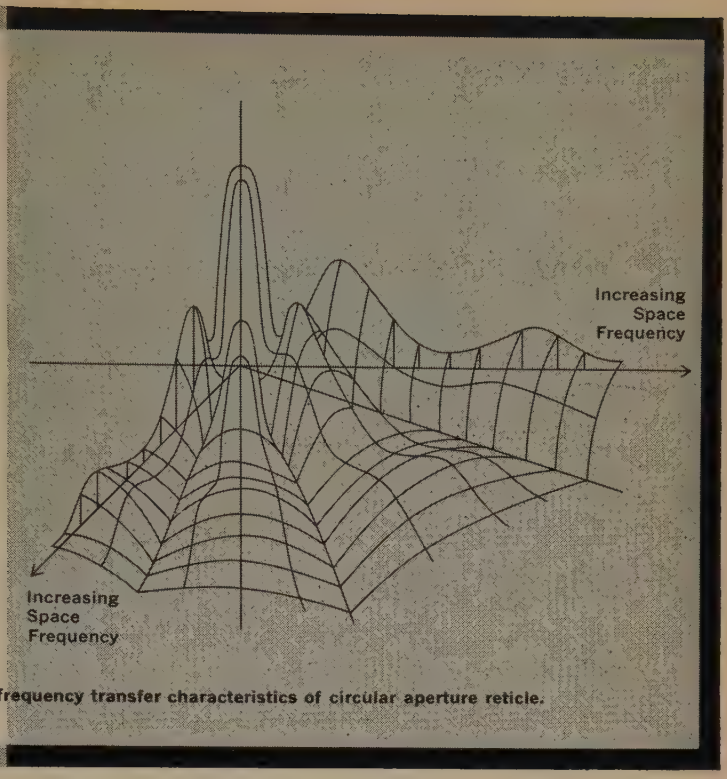
IRE CONVENTION INTERVIEWS

GPL will interview for the above positions during the IRE convention. Call Mr. Richard Hoffman at COlumbus 5-6138, 10 A.M.-6 P.M., March 23 thru 26.



Phosphor bronze reticle (actual size) and space frequency transfer characteristics of circular aperture reticle.

TARGET DISCRIMINATION IN INFRARED DETECTION SYSTEMS

The pioneering field of infrared detection offers many challenging opportunities to scientists and engineers at Ramo-Wooldridge for advanced studies in the solution of target discrimination problems. Research is continually under way at Ramo-Wooldridge in the integrating of infrared detection devices with the latest electronic systems techniques for enhanced target detection on the ground and in the air.

The phosphor bronze reticle, or image chopper, illustrated above was developed by Ramo-Wooldridge. It indicates a marked stride in space filtering discrimination concepts, and is used for target signal enhancement in guided missiles, anti-aircraft fire control and air collision warning applications.

The reticle is used in the focal plane of an infrared optical system and is rotated to chop the target image for the desired space filtering. It is also employed in time filtering, such as pulse length discrimination, or pulse bandwidth filtering.

Space filtering is critical to infrared systems, because of its ability to improve the detection of objects located in the midst of background interference. In a manner similar to that used in the modification of electronic waveforms by electrical filtering, space filtering enhances the two-dimensional space characteristics of a target. The size and features of the target are highlighted and the undesired background eliminated.

Scientists and engineers with backgrounds in infrared systems—or any of the other important areas of research and development listed below —are invited to inquire about current opportunities at Ramo-Wooldridge.

Electronic reconnaissance and countermeasures systems
Analog and digital computers
Air navigation and traffic control
Antisubmarine warfare
Basic research
Electronic language translation
Information processing systems
Advanced radio and wireline communications
Missile electronics systems

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a division of *Thompson Ramo Wooldridge Inc.*

Proven Performance!

View of microwave installation atop Mount Pico, Vermont. Altitude 4,000 feet.

. . . proven performance, where rough conditions are normal all year. Here is a high mountain-top tower where ANDREW equipment was installed to perform, exposed to 100 mph winds, driving sleet, ice and snow.

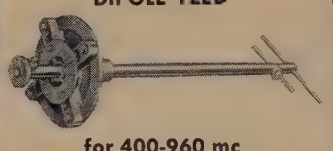
Selection of the best antenna systems for such problem installations is made easy through a choice of 30 ANDREW stock parabolic reflectors, which utilize the three standard microwave feeds. And tower work has been simplified too, with the new mount, which has separate elevation and azimuth adjustments for precise alignment.

All standard ANDREW antennas meet or surpass EIA recommendations and FCC specifications, governing radiation patterns and side lobes.

Uniform all weather performance is assured by the use of radomes and built in automatic de-icing equipment.

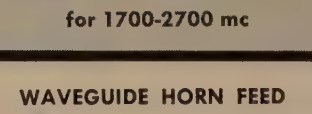
Why not check today on how you can get the maximum performance in your installation—just call the ANDREW Engineer in your area or write

DIPOLE FEED



for 400-960 mc

COAXIAL HORN FEED



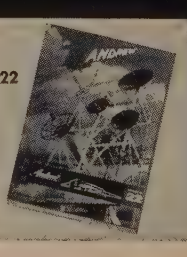
for 1700-2700 mc

WAVEGUIDE HORN FEED

for 3700-13,200 mc

ANDREW

Request Catalog 22 for complete description of 500 Antenna System Products



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ANTENNAS, ANTENNA SYSTEMS, TRANSMISSION LINES

INDUSTRY NEWS

SYMPOSIUM AT RAYTHEON

Microwave ferrite devices and solid state physics of ferrites were discussed by Raytheon scientists and over 50 representatives of government agencies at a symposium held in Waltham, Massachusetts on March 2 and 3.

Members of the research staff of Raytheon gave papers on ceramic research and ferrite devices. System applications were discussed in talks by members of Raytheon's Missile Systems, Government Equipment and Microwave & Power Tube Divisions.

A dinner held on March 2 featured Dr. W. Crawford Dunlap, speaking on "Solid State Physics in the USSR."

A high point of the conference came on the morning of March 3 with a round table discussion of service needs. This meeting was classified secret and covered many aspects of the systems applications required by the Defense Department over the near future.

Among the various papers given were: "Experimental Studies in the Microwave Properties of Ferrites" by Dr. Marshall Sirvetz; "Ceramic Research in Ferrites" by Dr. Seymour Blum; "Theoretical Interpretation of the Microwave Resonance Properties of Ferrites" by Dr. Ernst Schlömann; "Ferrite Devices and Their Applications" by Dr. H. Scharfman and Dr. Colin Bowness.

Agencies sending representatives included: Air Force Cambridge Research Center; BUSHIPS (Navy); Dept. of Defense; MIT Lincoln Laboratory; Naval Ordnance Lab., Corona, California; Naval Ordnance Lab., Silver Spring, Maryland; Naval Research Lab.; Office of Naval Research; U.S. Army Signal Supply Agency, Philadelphia; Rome Air Development Center; Signal Corps Electronics Lab., Fort Monmouth; Wright Air Development Center.

U.S. DIELECTRIC PRODUCTS, INC.

Formation of U.S. Dielectric Products, Inc., Leominster, Mass., is announced by Michael R. Levy, President. The firm, a subsidiary of Commonwealth Plastics Corp., will specialize in the design of prototype and production of plastic products for antenna, electronic, and aircraft use.

CIRCLE READER SERVICE CARD 18

RADIO ENGINEERING SHOW NEWS

• • •

OLARAD ELECTRONICS CORP.

BOOTHS 3208 - 3214

Among the new products to be hibited by Polarad Electronics orporation are:

A new line of self-contained mi-owave signal sources, 1050 to ,500 mc with integral power sup-y and interchangeable plug-in tun-g units.

A new spectrum analyzer, Model -84W, covering the range of 10 40,880 mc in a single self-con-ned unit and offering the choice dispersion bandwidths for wide d narrow pulse analysis.

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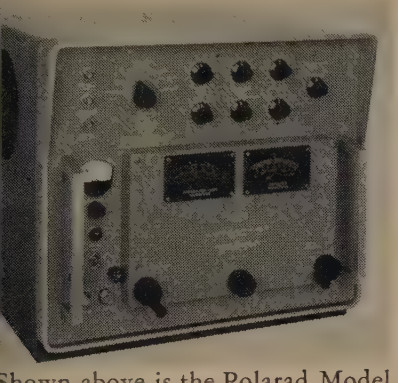

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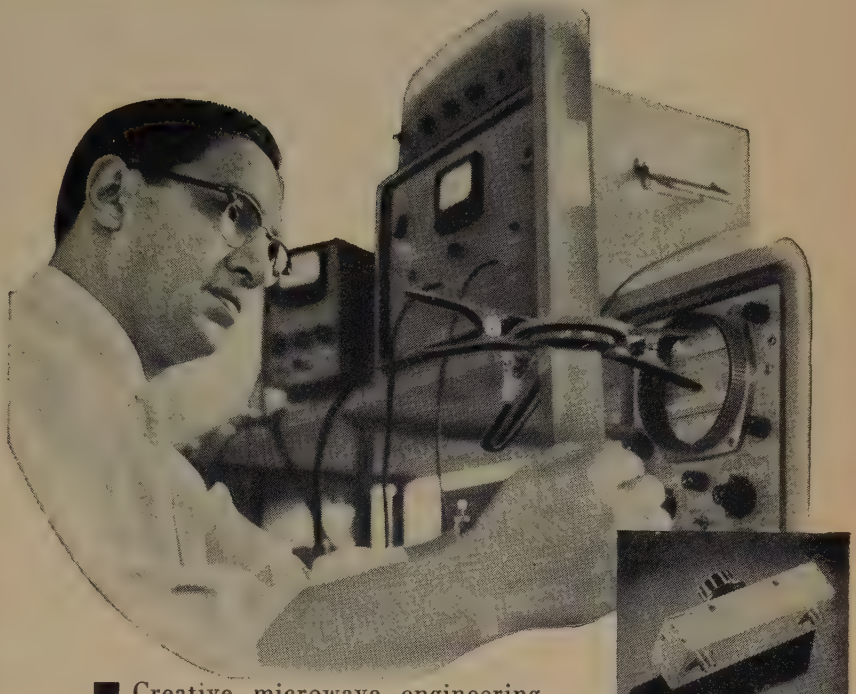

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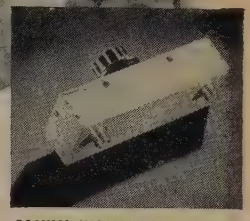

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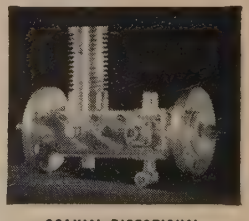

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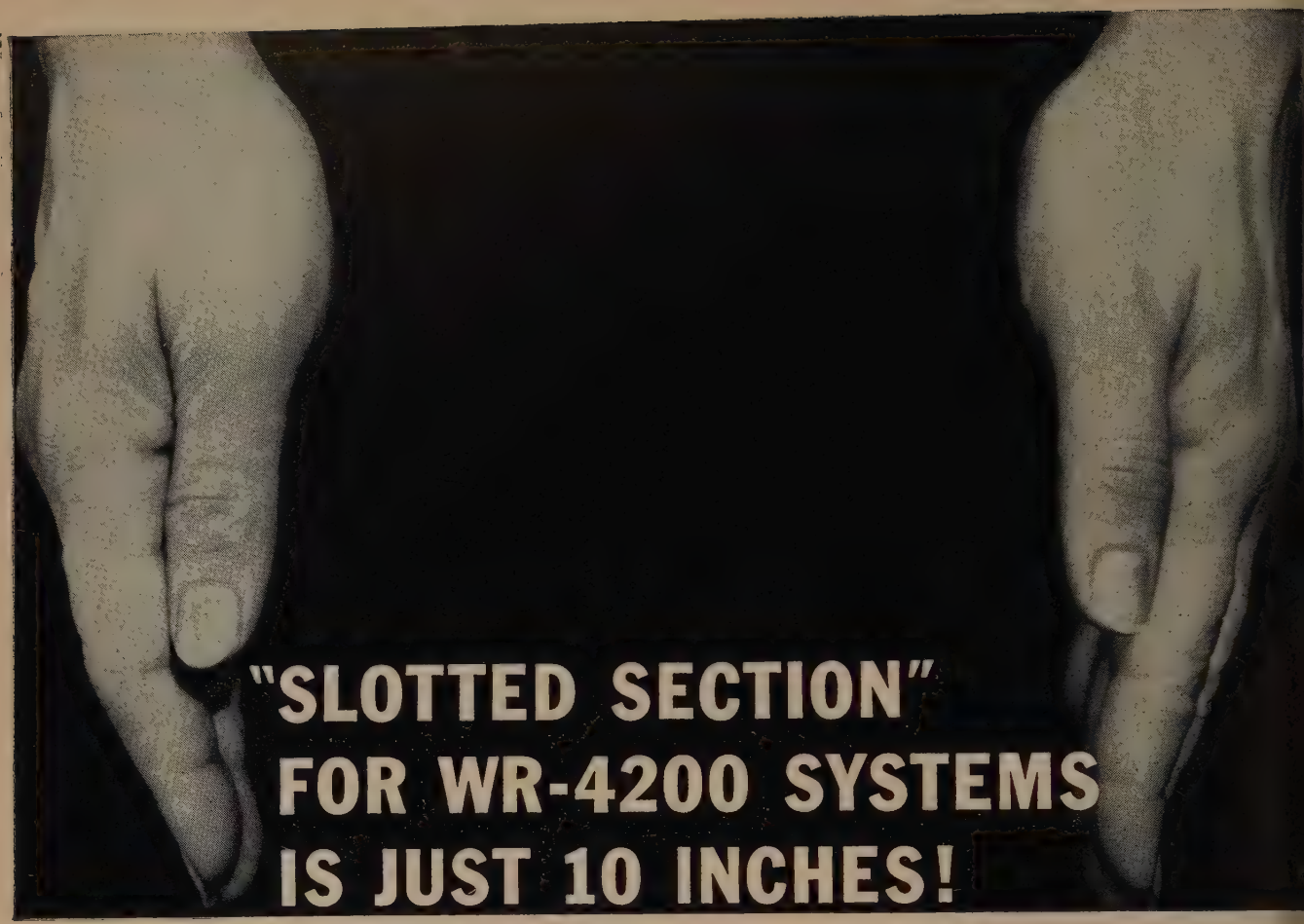

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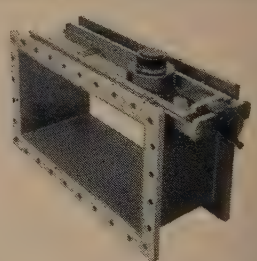

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CONTRIBUTORS' BIOGRAPHIES

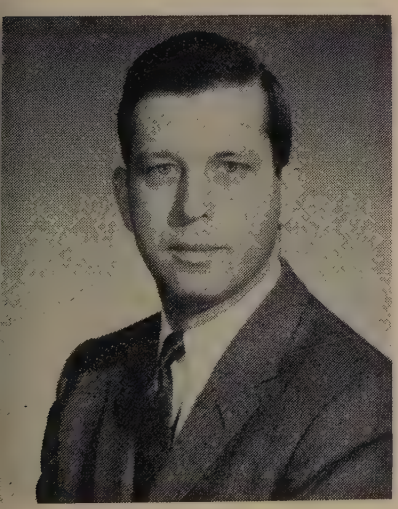
HUBERT HEFFNER was born in Lincolnton, N.C. on December 26, 1924. He received the B.S. degree in physics from Stanford University in 1947 and after a brief sojourn of graduate work in psychology received the Ph.D. degree in electrical engineering from Stanford in 1952. Between 1952 and 1954 he was a member of the technical staff of the Bell Telephone Laboratories where he was engaged in research on microwave electron tubes. In 1954 he joined the faculty of the Department of Electrical Engineering at Stanford University where he is now Associate Professor.

DR. HAROLD I. EWEN "Doc" Ewen was born in Springfield, Mass. on March 5, 1922. He received his B.A. in mathematics and astronomy from Amherst in 1943. After serving with the Naval Air Corps during World War II he entered the graduate school at Harvard University and received his Master's degree in 1948 and his Doctorate in physics in 1951.

His Ph.D. thesis work at Harvard was concerned with the measurement of the first signals at a unique radio frequency from interstellar matter and was related to radio emission from the ground state hyperfine levels of neutral atomic hydrogen at a frequency of 1420 Mc.

In 1952, Dr. Ewen founded the Ewen Knight Corporation, and in 1958, he founded the Ewen Dae Corporation. He is now the president of both corporations.

He is a member of Phi Beta Kappa and Sigma Xi and is a Fellow of the American Assn. for the Advancement of Science and the American Academy of Arts and Sciences.



SEYMOUR B. COHN is manager of the Electromagnetics Laboratory, Stanford Research Institute, Menlo Park, California. He is a native of Connecticut and in 1942 received his B.E. from Yale University. He then joined Harvard University's Radio Research Laboratory. In 1945 he entered Harvard on a fellowship and received his Ph.D. in Engineering Science and Applied Physics in 1948.

After leaving Harvard, Dr. Cohn joined Sperry Gyroscope Company, Great Neck, New York. In 1953 he joined the staff of SRI and became Manager in 1957.

He is a member of Sigma Xi, Tau Beta Pi, and the I.R.E. He is an Associate Editor of "the microwave journal" and has been an instrumental force in the publication since inception.

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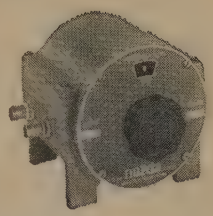

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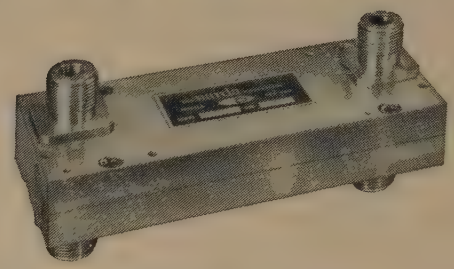

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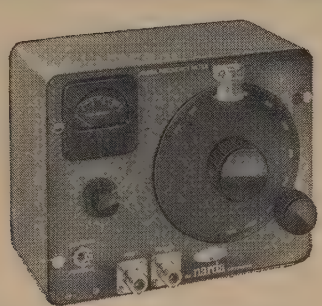
L	950-2000	3032	3.0 ± 0.25	1.2	20	6½x2½x⅞	225
S	2000-4000	3033	3.0 ± 0.25	1.2	20	5x2½x⅞	225



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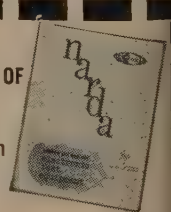

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MASERS and PARAMETRIC AMPLIFIERS

by

HUBERT HEFFNER

Stanford University

INTRODUCTION

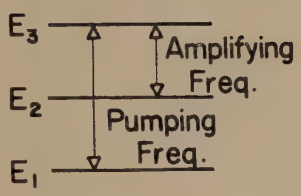
HE MASER and the parametric amplifier in their present forms now about two years old, still new ugh to excite our interest and en- siasm, but yet old enough so that can probably assess fairly their abilities and limitations. There is longer any doubt about their im- tance to microwave engineering, their proper use will make pos- e new experiments, new measure- its, new electronic systems which e inconceivable several years ago. the words "proper use" must be phasized, for these new amplifiers e a peculiar set of operating char- ristics unlike any of the other rowave devices with which we are iliar. Thus, in order to use them ctively, it is important that we not understand their capabilities in ns of the usually measured char- ristics, gain, bandwidth and noise re but also understand physically they operate, because what may ear to be a limitation for one ap- ation may be an advantage in her.

irst, let us ask how these new am- ers differ from the existing kly- n and traveling wave tube micro- e amplifiers with which we are iliar. There are two main differ- s:

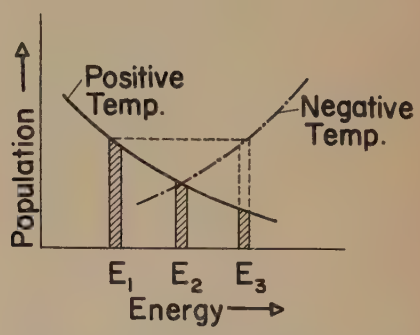
These amplifiers can use the perties of bound electrons rather free electrons.

They use r.f. energy rather than energy as a source of power for lification.

he first of these distinctions has ral interesting implications. The ous one is, of course, that we may put solid materials to work for us, but more important, by using the electrons bound to the atoms of a solid rather than the free electrons boiled off a hot cathode, we can build extremely low noise devices, for after all it is the temperature of the working substance which determines the amount of noise it produces.



ENERGY LEVELS



POPULATION DISTRIBUTION

Figure 1 — Energy levels and population distribution in a three level maser material.

Another implication of the use of bound electrons rather than free electrons is the great reduction in size possible. In a typical electron beam there are on the order of 10^8 electrons per cubic centimeter whereas in a solid the density of potentially usable electrons may be between 10^{19} to 10^{23} electrons per cubic centimeter. This difference of eleven to fifteen orders of magnitude allows us to dream more realistically of millimeter wave devices.

What are the properties of bound electrons which we might exploit? They have a mass, charge, and a magnetic moment. So far we have successfully used these last two characteristics for amplification and there is at least one proposal to utilize the negative effective mass of carriers in a semiconductor.

THE SOLID STATE MASER

The magnetic moments of the electrons in a solid are of course the basis for the operation of the solid state maser. When a material with atoms whose bound electrons produce a net magnetic moment is placed in a magnetic field there are only certain directions in which these magnetic moments can line up. Each direction corresponds to the possession of a definite amount of magnetic energy. In Fig. 1 are shown three such energy levels, and on the right are indicated the number of atoms in each direction. This is approximately the Boltzmann distribution with more atoms in a lower energy state than a higher state. If r.f. energy is applied at a frequency appropriate to the difference of energy between two of these levels, transitions of atoms from one energy state to the other will occur, transitions from a low level to a high level will absorb energy and transitions from a high to a low level will emit energy; but because there are more atoms in the lower levels, the net effect is one of energy absorption. This is the normal situation.

If now, however, we apply a strong

enough r.f. signal at a frequency appropriate to the energy difference between the lowest and the highest levels (this is called the pumping frequency) we can equalize the populations in these two levels. After doing this we are left with an in-between level which has a smaller population than the upper level. This can correspond to a Boltzmann distribution only if the temperature is made negative. Under some circumstances the population of the intermediate level can be made larger than that of the lowest level. The effective negative temperature description then applies to the populations of these two levels.

With this new population distribution, shown in Fig. 1, the application of r.f. energy at a frequency appropriate to the energy difference between levels 3 and 2 causes a net emission of energy since the high energy state is more heavily populated. In this way the input signal is enhanced and the maser substance becomes an amplifier.

The negative effective temperature which one can obtain is one of the most important parameters of the maser, for it indicates not only how much gain the sample can yield but also is a measure of the noisiness of the amplifier. It can be written as

$$T_{eff} = -T\left[\frac{w_{12}\nu_{21} + w_{23}\nu_{32}}{w_{12}\nu_{21} - w_{23}\nu_{32}}\right] \qquad (1)$$

Here T is the actual temperature of crystal, ω_{nm} is the thermally induced transition probability from energy level n to energy level m and ν_{nm} is the frequency corresponding to the energy difference between levels n and m. (Figure 1 has been drawn assuming $w_{12}\nu_{21} > w_{23}\nu_{32}$). Under the crude but not too unrealistic assumption that all transition probabilities are approximately equal the effective temperature is

$$T_{eff} \simeq -T\frac{\nu_{32}}{\nu_{21} - \nu_{32}} = -T\frac{\nu_{32}}{\nu_{31} - 2\nu_{32}} \qquad (2)$$

Thus in order to get a small negative effective temperature (large population imbalance) we need to have the pumping frequency, ν_{31}, much larger than the amplifying frequency ν_{32}.

The power emitted by the sample in response to the incident input power is

$$P_e = \frac{N h^2 \nu_{32}}{n k |T_{eff}|} W_{32} \qquad (3)$$

where N is the total number of magnetic ions in the sample; h, Planck's constant; n, the number of low lying magnetic energy levels (three in Fig. 1); k, Boltzmann's constant; and W_{32} is the induced transition probability. This induced transition probability depends upon the material properties and upon the strength of the incoming signal so that Eq. (3) shows linear amplification.

Instead of considering the power emitted, one usually describes the performance of a maser in terms of the energy stored in the structure divided by the power emitted. If this power were absorbed rather than emitted this would be just the standard definition for quality factor or Q. Thus it is reasonable to consider the maser to have a negative Q, usually called the magnetic Q. It is given by

$$-Q_{mag} = \frac{1}{\rho}\frac{C}{F}T_{eff} \qquad (4)$$

where ρ is the density of magnetic ions is the sample, C is a constant depending upon the material properties,* and F is the filling factor, a measure of how completely the r.f. magnetic field in the structure is usefully concentrated in the sample.

A low magnetic Q is desired since this implies large power emitted and Eq. 4 shows that this is obtained with a low effective temperature. Magnetic Q's of the order of 100 to 1000 are typical with present maser materials.

The noisiness of the maser is also related to its effective negative temperature. In fact if the losses in the maser structure are negligible the amplifier noise temperature is just equal to the magnitude of this effective negative temperature. In other words, the noise figure is then given by

$$F = 1 + \frac{T_{source}}{|T_{eff}|} \qquad (5)$$

This briefly is how the maser operates. It requires first of all a piece of material which when placed in a d.c. magnetic field has appropriate magnetic energy levels. It requires a structure to provide the strong r.f. magnetic fields necessary at both the pumping and amplifying frequencies and normally it requires liquid helium to cool the maser material down to a point where competing thermal processes do not mask the effect we are trying to use.

The requirement for liquid helium is both a nuisance and a blessing. Its nuisance value is obvious, it is expensive, difficult to use and greatly complicates the device. Its blessing is that at this temperature the noisiness of the device is negligible.

The solid state cavity maser using paramagnetic resonance was first proposed by Bloembergen at Harvard in 1956 although two Russians, Basov and Prokharov antedate him by almost two years in proposing a similar amplifier using molecular resonance in solids and J. Weber proposed using population inversion for microwave amplification as long ago as 1952. The first working maser was built by Scovil, Feher and Seidel at the Bell Telephone Laboratories, and the most extensive experimental investigations were made by McWhorter, Meyer and their colleagues at the Lincoln Laboratory.

Both the maser and the parametric amplifier in their simplest form behave as negative resistances across the cavities in which they are placed. This means that they are forms of a regenerative amplifier and as such have a square root of power gain times bandwidth which is a constant. In the case of the one port cavity maser, this gain bandwidth product is inversely related to the effective temperature or more simply to the magnetic Q. The maximum gain bandwidth product is given by

$$\text{gain}^{\frac{1}{2}} \times \text{fractional bandwidth} = \frac{2}{Q_{mag}} \qquad (6)$$

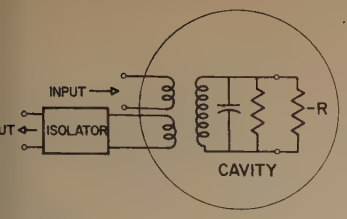
Most cavity masers have gain bandwidth products approaching this maximum value quite closely.

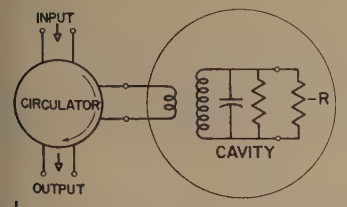
Since both of these amplifiers are regenerative they are highly sensitive to variations in load impedance so that some form of non-reciprocal element either an isolator or circulator, as shown in Fig. 2, must be used to form a stable amplifier. The circulator serves another purpose too, by keeping the noise produced by the relatively hot load from entering the maser there to be amplified and returned.

*This constant is

$$C = \frac{nk}{32\pi^2 \langle 2|M_x|3\rangle^2 T_2}$$

where $\langle 2|M_x|3\rangle$ is the matrix element of magnetic moment joining states 2 and 3, T_2 is the spin-spin relaxation time, a measure of the 3, 2 resonance line width, and as before n and k are the number of low lying magnetic energy levels and Boltzmann's constant respectively.





$N)^{\frac{1}{2}} \times$ (FRACTIONAL BANDWIDTH) = CONSTANT

ure 2 — Methods of utilizing the effec-ive negative resistance produced by naser or parametric action.

MASER CAPABILITIES

Let us now turn to the experimental ults reported on maser amplifiers. low are listed the characteristics of S-band maser built by the Lincoln oratory group.

TABLE A

TYPICAL CAVITY MASER PERFORMANCE

terial:	$K_3Co(CN)_6$ with ½% Cr
np:	15 mw at 9000 mc.
nal:	3000 mc.
rput:	3 μw
n:	30 db
dwidth:	50 kc
ser Noise Temp.:	2°K (F = 0.03 db)
tem Noise Temp.:	25°K (F=0.35 db)

te the following characteristics: pump power must be supplied at higher frequency than that to be plified, second, the bandwidth is ex-mely small, third, liquid helium st be used, and fourth, the noise fig- is fantastically low. Let us take these points one by one.

First, is it necessary to provide a her frequency pumping signal? The wer is no. If this requirement is a problem, there are ways by which can build masers which can be nped at a frequency lower than that be amplified.

econd, can we increase the band-dth? The answer is yes. We can in-ase it somewhat by using a differ-material. The use of chrome doped phire (ruby), for instance might rease the gain-bandwidth product a factor of two to ten. This is still ll, so we must look to some other eme for appreciable bandwidth maser amplifiers. That scheme involves the use of a propagating circuit rather than a cavity. Such an amplifier is called a traveling wave maser. One of the advantages of the traveling wave version is that in addition to the broader bandwidth obtained, the process of amplification can be made non-reciprocal.

The gain of the traveling wave maser per unit length is also related to the effective temperature. In fact, the

$$\text{gain per unit length} = \frac{27}{\lambda}\frac{c}{v_g}\frac{1}{Q_{mag}} \text{ db} \qquad (7)$$

where λ is the free space wavelength and v_g/c is the ratio of group velocity to velocity of light. Typically v_g/c must be very small in order to have appreciable gain.

The maximum bandwidth, $\triangle f$, which goes with the peak numerical gain, G, is related to the line width of the material, $\triangle f_s$. It is

$$\triangle f = \left[\frac{\ln 2}{\ln G - \ln 2}\right]^{\frac{1}{2}} \triangle f_s \qquad (8)$$

As one can see gain-bandwidth product is no longer a constant. Typical values of line width, $\triangle f_s$, for paramagnetic maser materials vary between 5 to 100 mc. For an amplifier with 20 db gain the corresponding maximum amplification bandwidth would be between 4 and 40 mc. The actual bandwidth could be less if the traveling wave structure with its matching sections is itself narrower in bandwidth.

In table B are listed the performance characteristics of a traveling wave maser using ruby built by the Bell Telephone Laboratories group.

TABLE B

TRAVELING-WAVE MASER

Material:	Al_2O_3 with 0.05% Cr
Pump:	18.9 - 19.5 kmc (100 mw)
Signal:	5.9 kmc (tunable over 350 mc)
Output:	6 μw c.w. (at saturation) 6 mw. pulsed (at saturation)
Gain	23 db
Reverse loss	29 db
Bandwidth	25 mc.

Note that the reverse loss is greater than the forward gain. This was achieved by a clever use of the polarization properties of the comb-type slow wave circuit used. For this circuit the reverse wave has opposite polarization to the forward wave. The introduction of a second heavily doped ruby sample can be used to attenuate this wave while leaving the oppositely polarized forward wave unaffected. Note also that the saturated pulsed power output is three orders of magnitude larger than the saturated c.w. output. This perhaps unexpected result arises because all of the spins may be made to flip in a very short time to give up their accumulated energy rapidly. Although the noise figure of this amplifier has not yet been measured, there is no reason to believe that it will differ appreciably from the cavity versions.

Let us now consider the next maser characteristic mentioned, the requirement for liquid helium. Is it possible to operate masers at room temperature? We can shed some light on this question by referring to eq. 2, the relation for the effective negative temperature. This quantity, we remember, had to be small in order to obtain reasonable gain bandwidth behavior and low noise performance. It is directly proportional, however, to the actual crystal temperature T. Thus if we increase T by two orders of magnitude to arrive at room temperature, we must decrease the other factor in the equation by the corresponding amount. This can be done by raising the pumping frequency, ν_{31}. An increase of two orders of magnitude puts us in the optical, or more precisely, the far infra-red region of the spectrum. The question as to whether this technique will be practical is still unresolved but is being pursued at a number of laboratories.

We can afford to increase the temperature some without employing such drastic means as these. A group at the Radar Research Establishment in England has successfully operated a ruby maser near liquid nitrogen temperature without using any special techniques. The performance however was degraded by about the factor of 10 or 20 which represents the temperature ratio.

The final maser characteristic mentioned was the extremely low noise figure. It is wise to ask whether such a low noise amplifier can be effectively used. Except for certain radio astronomy applications it probably cannot. Inherent antenna noise temperature and loss in the transmission system seem to make the reduction of amplifier noise temperatures below about

40° of marginal utility in communications systems. It is for this reason that the parametric amplifier looks so much more attractive to the systems engineer.

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THE PARAMETRIC AMPLIFIER

Let us now consider the parametric amplifier. The principle of operation is not really new. As far back as the 1880's Lord Rayleigh was writing about electrical oscillations induced in a circuit in which the capacitance was varied with time. What is new is the successful application of the parametric principle at microwave frequencies.

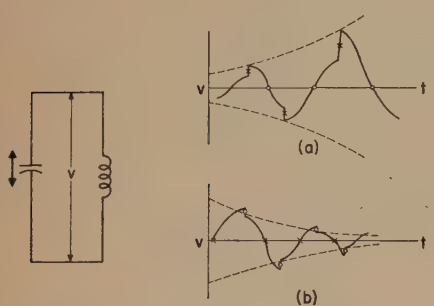


Figure 3 — A simple resonant circuit whose capacitance can be varied with time. Variation at twice the resonant frequency can amplify or attenuate a signal depending upon its phase.

Unlike the maser which can be explained only by invoking the principles of quantum mechanics, the parametric amplifier can be explained purely in terms of classical circuit concepts. We can illustrate how it works in its simplest form by reference to Fig. 3. Here is a simple L-C resonant circuit in which we imagine we can physically grasp the condenser plates and pull them apart. At the upper right is shown the voltage across the condenser as a function of time. Imagine that when the voltage is a maximum we suddenly pull the plates apart. We do work in separating the charge and work goes into increasing the voltage. Now, just as the voltage goes through zero and there is no charge on the plates we push them back to their original position. No work is done and the voltage is unchanged. When the voltage is a negative maximum we again pull the plates apart, and so on. In this way a signal at the resonant frequency is amplified by the changing capacitance. By coupling in an input circuit and a load, we have a parametric amplifier. Note the following three points, however.

First, our pushing or pulling, that is the capacitance variation must be at a frequency which is twice that of the resonant frequency of the L-C circuit.

Second, in order to amplify, we must be careful to pull apart when the voltage is maximum and push together when it is zero. If we do the opposite, the signal is attenuated. Another way of saying this is that this amplifier is phase sensitive. The phase of the capacitance variation frequency, (we shall call this the pumping frequency) must be adjusted relative to the phase of the signal in order to amplify.

Third, we might just as well have varied the inductance rather than the capacitance and achieved the same result.

This circuit is often called a two-frequency or degenerate parametric amplifier. Its phase sensitivity is usually a drawback but for certain applications can be turned into an advantage.

As an example, consider what happens when we introduce a signal whose frequency is slightly different from ω, the value which is just half the pumping frequency. We can treat this signal as though it were at the exact half frequency ω but had a time varying phase at the difference frequency. Thus as the phase changes, the amplifier, as we have seen, alternately amplifies and attenuates. The output then is an amplified signal, amplitude modulated at the difference frequency. Another way of describing this is that if the incoming signal is treated as a single sideband, the amplifier inserts the other sideband. This behavior coupled with low-noise characteristics makes this form of the amplifier attractive for use in doppler radar receivers and in reception of single sideband transmission as employed in scatter communication.

Since the device either amplifies or attenuates depending upon the phase relations between pump and signal, it can be looked upon as two state element making it suitable for computer use. Indeed, Japanese workers have recently used a low frequency version in an experimental computer.

For most applications, however, this phase sensitivity is a disadvantage. We can overcome this sensitivity by adding another resonant circuit termed the idling circuit as shown in Fig. 4. Here we have two resonant circuits

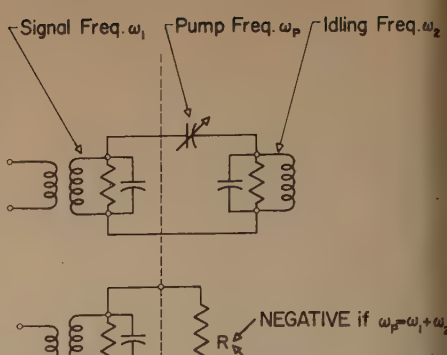


Figure 4 — A three frequency parametric amplifier.

coupled together by a time varying energy storage element shown here as a capacitance. The dual of this circuit in which the coupling element is a time varying inductance is also a parametric device and has the same characteristics.

The capacitance is caused to vary at the pumping frequency, ω_p, and the tuned circuits are resonant at what is termed the signal frequency, ω_1, and the idling frequency, ω_2. We can distinguish two different cases of interest, one in which the pump frequency is the sum of the signal and idle frequencies, and the other in which it is the difference between the signal and idle frequencies. In the former case of sum frequency pumping the coupling capacitance and idle circuit look like a negative resistance to the signal circuit while in the latter case of difference frequency pumping they look like a positive resistance.

Three of the six possible cases of sum and difference pumping are shown in Fig. 5. Here the broad line represents the pump frequency, the thin solid line the signal frequency and the dotted line the idle frequency. The upper situation is typical of the sum pumped parametric amplifier. Because of the effective negative resistance which is produced by sum frequency pumping, this circuit can amplify. Moreover, if the output is taken not at the signal frequency but at the idling frequency it is a converter with conversion gain. It is, however, unstable. If the negative resistance is made too large relative to the resonant circuit loading, the device will oscillate. You will notice that the signal frequency is placed lower than the idle frequency rather than vice versa. Although either arrangement can lead to useful amplification, one can show that

situation illustrated leads to the vest noise figure.

This type of parametric amplifier be described in much the same y as was the maser. The time vary- energy storage element which to- her with the idling circuit gives e to the negative resistance may be resented as having a negative $=-Q_p$. The magnitude of this gative Q is given by

$$Q_p = \frac{1}{Q_{l2}\left(\frac{\Delta C_D}{C_D}\right)^2 F_1 F_2} \tag{9}$$

ere Q_{l2} is the loaded Q of the idling cuit, $\frac{\Delta C_D}{C_D}$ is the peak-to-peak ctional change in the energy stor- element (assumed to be a capaci- ce) produced by the pump source d F_1 and F_2 are filling factors in the nal and idle circuits — measures of fraction of the total circuit ca- itance represented by the steady acitance associated with the variable ment.

The gain, bandwidth and noise fig- can all be written in terms of this ative Q and the various Q's of the plifying and idling circuits. Let us ne

= the Q of the signal circuit loaded by the input and output circuits

= the unloaded Q of the signal circuit

= the external Q of the input circuit

= the external Q of the output circuit

= signal angular frequency

= idle angular frequency

n the power gain of a two-port plifier such as that shown at the top ig. 2 is

$$\text{gain} = 4\left(\frac{Q_{L1}}{Q_{ei}}\frac{Q_p}{Q_{eo}}\right)\frac{1}{Q_p - Q_{L1}} \tag{10}$$

product of square root power and relative bandwidth is a con- t as it was in the case of the maser. high gains this relation is

$$\text{Gain}^{\frac{1}{2}} \times \text{rel. bandwdith} \simeq \frac{2}{Q_{L2}}\frac{\omega_2}{\omega_1}\left(\frac{Q_{ei}}{Q_{e1}}\frac{Q_{eo}}{Q_{e1}}\right)^{\frac{1}{2}} \tag{11}$$

noise figure of the parametric plifier is

$$F = 1 + \frac{Q_{ei}}{Q_{u1}} + \frac{Q_L}{Q_{e1}}\frac{\omega_2}{\omega_1} \tag{12}$$

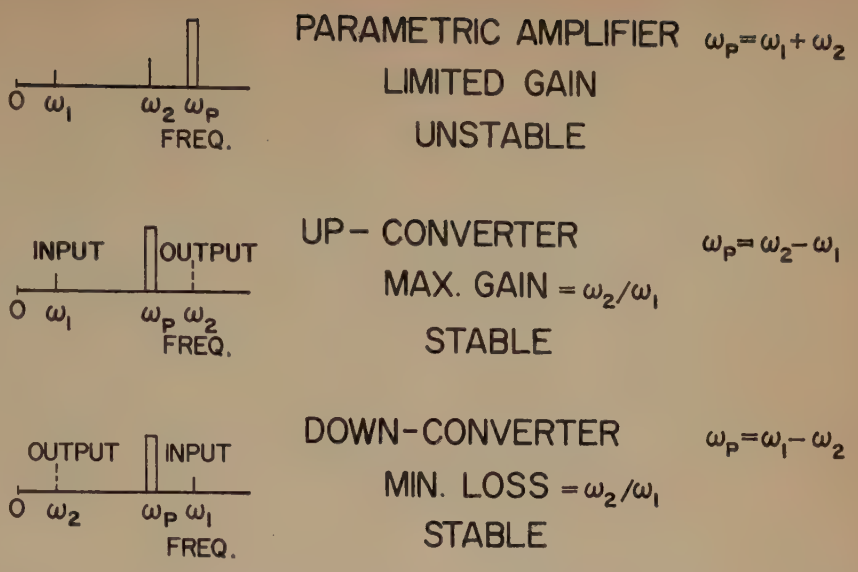


Figure 5 — Spectra illustrating various types of three-frequency parametric operation.

We see that if the amplifier is loaded very heavily by the input this noise figure can approach its minimum value

$$F_{min} = 1 + \frac{\omega_1}{\omega_2} \tag{13}$$

Note that both the noise figure and the gain-bandwidth product are improved by making the ratio of idling frequency to signal frequency large.

We must be extremely careful in talking about the noise figure for, unlike any of the conventional amplifiers, noise figure alone is not a good description of the parametric amplifier's noisiness. The reasons for this are twofold. First, the noise figure definition involves the concept of a matched amplifier and because the parametric amplifier obtains its gain from a negative resistance effect, the output can seldom if ever be matched to the load unless a circulator is used. Without a circulator, the noise power from the load incident on the amplifier is amplified and returned to the load. Under these conditions Eq. 12 does not tell the full story for it neglects this amplified load noise. There are two ways of surmounting this difficulty; one, as mentioned, is to use a circulator as shown at the bottom of Fig. 2, the other is to couple the load very lightly to the amplifier. This latter solution improves the noise properties at the expense of gain-bandwidth product.

The second shortcoming of the noise figure definition is a more subtle one and actually involves a misuse of the definition. It rests upon the fact that the parametric amplifier actually amplifies at two frequencies, the signal frequency and the idle frequency. Normally no confusion results from this fact, but in the degenerate case where signal and idle frequency bands overlap, it can. In this case a single signal frequency if it differs at all from half the pump frequency produces not only an amplified replica of itself in the amplifier output but also an idling frequency output component slightly displaced. To make a true amplifier this idling frequency component must be filtered out. In either case, however, the signal input appears at only the signal frequency while noise enters at both signal and idle frequency. With two essentially equivalent channels for noise and only one for signal one sees that the minimum noise figure for this degenerate amplifier ($\omega_1 = \omega_2$) is 2 or 3 db as Eq. 13 predicts. Often however, noise figures of the degenerate amplifier are quoted neglecting this effect and would be true values only if signal were simultaneously placed on both input channels — a difficult modulation technique. In the future such measurements will be labeled as two channel noise figures. One must add a minimum of two (numerically) to such figures to obtain a true noise figure appropriate to conventional single channel signal amplification.

THE PARAMETRIC UP-CONVERTER

The lower two diagrams of Fig. 5 represent difference frequency pumping. Because the signal circuit is loaded by an effective resistance which is positive, no amplification at that frequency can occur. If the output is taken at the idling frequency, however,

we can obtain conversion gain. Manley and Rowe have shown very generally that the conversion gain in such a case can be as much as the ratio of the output to input frequencies. Thus, the up-converter in which the output frequency is higher than the input frequency can have conversion gain while the down-converter in which the opposite frequency ratio holds has conversion loss. These devices are completely stable.

Normally what is wanted is an amplified output not converted up in frequency but rather at the original signal frequency or possibly converted down in frequency. Such an output can be obtained by following the up-converter with a *resistive* mixer. If the gain of the parametric up-converter is sufficient, *i.e.,* a large enough ratio of output to input frequency, the overall gain and noise figure will not suffer greatly from the loss of this subsequent mixing stage.

With the present state of the art, such up-converter systems are probably limited to use with input signal frequencies below 1000 mc or so. They are particularly attractive in the U.H.F. region where their great advantage of stability and relatively broad bandwidth make them serious competitors to the standard parametric amplifier.

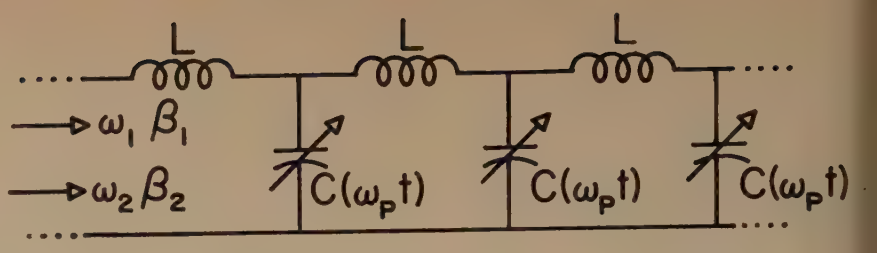
THE TRAVELING WAVE PARAMETRIC AMPLIFIER

Probably the most promising type of parametric device is the traveling wave version of the parametric amplifier. Unlike the regenerative cavity version, it is capable of large bandwidth and unilateral amplification while retaining the low noise behavior which has proved so attractive.

A schematic diagram of the traveling wave amplifier is shown in Fig. 6. In its simplest form it is composed of a transmission line whose shunt capacitance per unit length is caused to vary by means of a progressive wave at the pump frequency, ω_p, having a phase constant β_p. P. K. Tien has analyzed this circuit in great detail but we shall quote only a few of his results. Tien finds that if a signal and an idle frequency wave can propagate on the circuit whose frequencies and phase constants are

$$\omega_1 + \omega_2 = \omega_p$$
$$\beta_1 + \beta_2 = \beta_p$$

then the amplification at the signal and the idle frequencies can occur. Moreover this amplification is non-reciprocal and takes place in the direction in which the pump wave is flowing.



AMPLIFICATION IF:

$$\omega_1 + \omega_2 = \omega_p$$
$$\beta_1 + \beta_2 = \beta_p$$

Figure 6 — Schematic diagram of a traveling wave parametric amplifier.

The gain per unit length is given by

$$\text{power gain} = 0.542 \frac{\Delta C_D}{C_D} \times (F_1 F_2 \beta_1 \beta_2)^{1/2} \text{ db.}$$

Care must be taken that the circuit does not propagate a wave at the upper sideband, $\omega_p + \omega_1$, or $\omega_p + \omega_2$ or at the harmonics of the signal and idle frequencies for if it does, the gain can be seriously reduced. In spite of these difficulties, the traveling wave version appears highly attractive.

THE PARAMETRIC ELEMENT

At this point we should perhaps stop and ask ourselves what means are available to us to obtain time varying energy storage elements at microwave frequencies. Suhl's original microwave parametric amplifier proposal involved the use of ferrite to obtain an effective time varying inductance. Since then two other methods have been successfully employed; the use of back-biased semiconductor diodes and of electron beams. In addition, use of the Hall effect in semiconductors and of the ferroelectric effect have been proposed but discarded at least temporarily for use at microwave frequencies. Use of cyclotron resonance in semiconductors has also been proposed and may prove attractive.

Ferrimagnetic material can in a sense behave like a time varying inductance because of the non-linear equation the magnetization obeys.

$$\frac{\vec{dM}}{dt} = \gamma \vec{M} \times \vec{H}$$

An important figure of merit for ferrite materials as parametric amplifiers is the ratio of resonance line width to saturation magnetization. The larger this ratio is, the larger will be the maximum gain bandwidth product obtainable as an amplifier, but also the larger the pumping power required to achieve amplification. The ferrite may be used in several ways depending upon whether the signal and idle resonances are obtained by means of cavity resonances or internal spin-wave resonances in the ferrimagnetic material itself. Utilization of the internal resonances leads to better filling factors and hence lower pumping powers. Even so, the powers required are several orders of magnitude larger than those required with diodes. Moreover, a d.c. magnetic field is required for proper bias of the ferrite. For these reasons it seems that the ferrimagnetic amplifier is less attractive than the semiconductor diode.

What then of the other two forms of variable elements, the back-biased diode and the electron beam? Where do they stand in the competition? Let us consider the diode first.

Fig. 7 shows the equivalent circuit of a back biased diode. It can be represented by a voltage sensitive barrier capacitance C_D in series with a small spreading resistance, R_s. The main figure of merit for the diode as a parametric amplifier element is the Q defined as $Q_D = 1/\omega C_D R_s$. Parametric amplifiers can be made to operate up to a frequency where the Q is of the order of unity. The frequency where the Q is unity is usually termed the cut-off frequency.

Recent measurements have tended to cast doubt on the constancy of the spreading resistance with frequency. More experimentation is necessary before this question can be resolved satisfactorily.

Diodes with cut-off frequencies in e vicinity of 70 kmc are currently ing made and cut-off frequencies of e order of 1000 kilomegacycles seem asonable. Thus there seems to be no r to extending the parametric amification principle well into the milmeter wave range.

The cut-off frequency, or equivantly, the diode Q is important too in etermining the noise figure of the nplifier. The higher the Q at a given equency, the lower the noise figure.

In addition to ferrites and semiconctor diodes, electron beams may be sed to produce the variable energy orage element needed for parametric nplifiers. Several schemes using elecon beams have been proposed both of e cavity and traveling-wave type emoying both longitudinal and transrse modulation. In spite of the inial disadvantage of starting with an ectron beam containing a relatively rge amount of shot noise which the lid state versions do not possess, me of these schemes, particularly ose using transverse modulation, apar to be competitive with the semiductor diode.

At this point, however, it is the miconductor diode which holds the ad. It is physically small, it does not quire a magnetic field as do the fere and beam versions, it does not reire the large pump powers which e ferrite elements do, it does not have e shot noise limitation of the elecon beam, and unlike the electron am, can be cooled below room temrature to minimize its thermal noise ntribution.

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EXPERIMENTAL RESULTS

In such a fast moving field as this, e always faces the danger when quotg experimental results of finding the ta almost obsolete shortly after their blication. Bearing this pitfall in nd, let us look at the performance aracteristics of some of the paraetric devices which have been ieved so far.

Many laboratories have built cavityoe parametric amplifiers at frequens ranging from the low u.h.f. reon through C band. Table C gives tain representative performance figes for three types of amplifiers. yet, no noise figure measurements of the ferrite amplifiers have been reported.

The most extensive work on the upconverter has been done by a group at the Airborne Instruments Laboratory. The following table gives an indication of the performance currently obtainable with this type of parametric device.

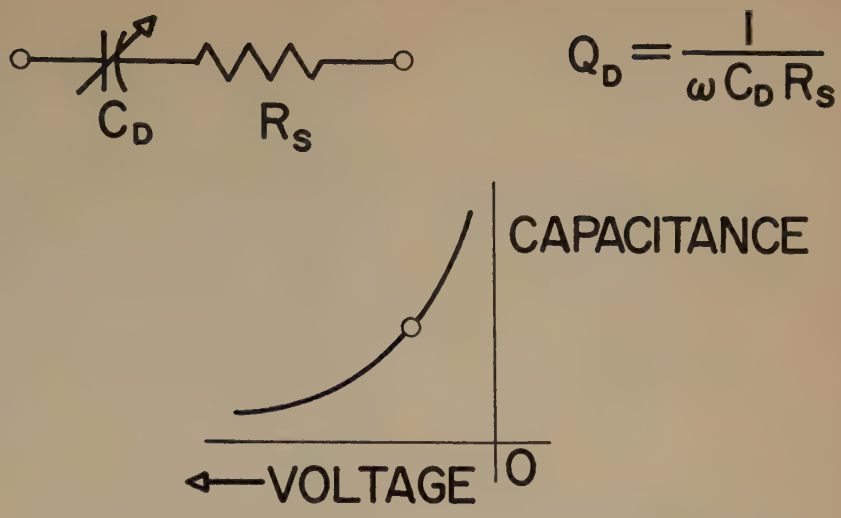

Figure 7 — Equivalent circuit of the back-biased semiconductor diode.

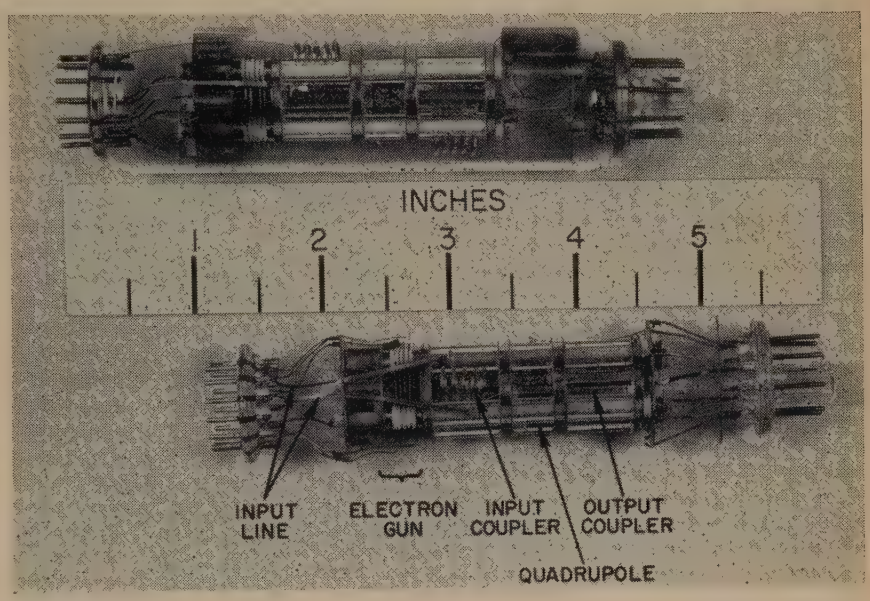

Figure 8 — Photograph of the Zenith electron-beam parametric amplifier mentioned in Table C.

TABLE C

CAVITY PARAMETRIC AMPLIFIER PERFORMANCE

Type	Semiconductor diode	Mn. Ferrite	Electron Beam
Place	Stanford University	Bell Labs	Zenith
Pump Freq.	4100	9000 mc	900 mc
Pump Power	15mw	3 kw (pulsed)	10 mw
Signal Freq.	1420 mc	4500 mc (degenerate)	450 mc (degenerate)
Gain	27 db	25-30 db	20 db
Bandwidth	200 kc	2 mc	10 per cent
Noise Figure	3.3 db	?	3.7 db (1.3 db two channel)

TABLE D

UP-CONVERTER PERFORMANCE

Type	Semiconductor diode
Place	Airborne Instruments Lab.
Pump Freq.	8900 mc.
Pump Power	100 mw.
Signal Freq.	400 mc.
Output Freq.	9300 mc.
Conversion Gain	11 db
Bandwidth	10 per cent
Noise Figure	1.9 db

As yet, very little work has been done on the traveling-wave parametric amplifier. An indication of the advantages of this version can be obtained by comparing the results shown in Table E of the first traveling wave type built at the Bell Telephone Laboratories with the performance of the cavity versions quoted earlier.

TABLE E
TRAVELING-WAVE-TYPE PERFORMANCE

Type	Semiconductor Diode
Place	Bell Telephone Laboratories
Pump Frequency	900 mc
Pump Power	10 mw
Signal Frequency	400 mc (degenerate version)
Gain	10 db
Bandwidth	25 per cent
Noise Figure	3.5 db

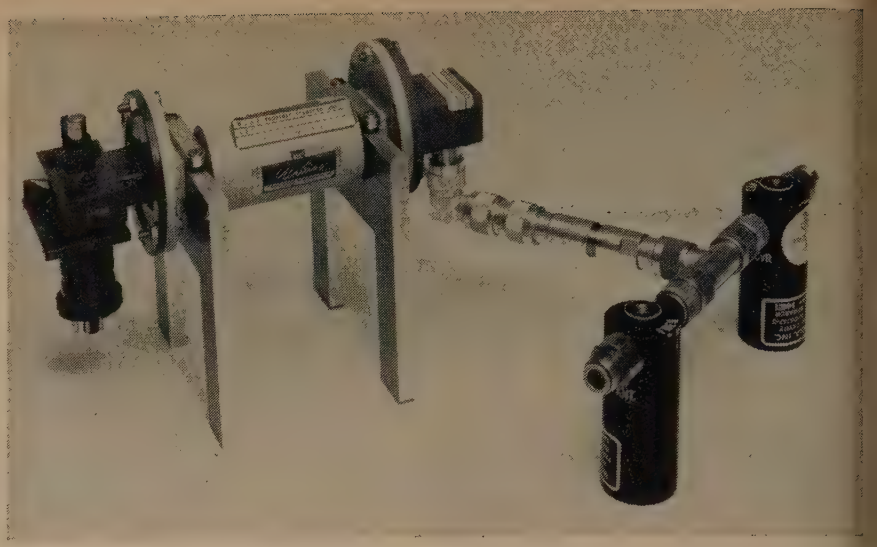

Figure 9 — A standard three-frequency cavity-type parametric amplifier and oscillator. Pump power at 7.0 Kmc/s is supplied by the klystron oscillator. The two cavities are tuned to 3.1 and 3.9 Kmc/s. The nonlinear-capacitance diode is in the line between the pump and the two cavities. Amplification and later oscillation at both lower frequencies are obtained as the pump power level is raised.

CONCLUSION

Undoubtedly the maser and particularly the parametric devices are destined to play an important role in microwave systems. The maser with its near ultimate in noise figure is perhaps less effectively usable than the parametric amplifier and certainly the liquid helium requirement is a drawback. Nevertheless, one should not count the maser out, for new materials, new techniques and new ideas may well suddenly appear which will eliminate many of the current maser disadvantages.

The parametric amplifier seems to offer practical means of providing amplification with as low a noise figure as microwave systems can effectively use. In particular, the traveling wave version seems to have all the desirable characteristics, bandwidth, unilateral amplification, and low noise which are needed in today's applications.

Much remains to be done — investigations of new materials, new ways of using population inversion, new ways of exploiting the peculiar characteristics of the parametric devices, and many more. At the same time, we should be on guard for the appearance of some entirely new phenomenon or some entirely new way of exploiting materials which will lead to equally far reaching advances in microwaves.

EDITOR'S NOTE: *A recent issue of "the microwave journal" presented a treatment of the solid state maser by William From. In the opinion of the editors, Dr. Heffner's approach to the subject of masers offers additional information on this device to our readers.*

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A THERMODYNAMIC ANALYSIS OF MASER SYSTEMS

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0 INTRODUCTION

The development of low noise solid ate amplifiers has created consider- ble excitement in the field of micro- ave radiometry, particularly in its ap- ication to radio astronomy. The lit- ature is now fairly well populated ith descriptive information concern- g these exotic new devices. Some ther startling predictions have been ade concerning system performance pabilities, when enhanced by such vices. Within the coming year, many search groups will be operating mi- owave systems incorporating low in- rnal noise solid state amplifiers.

Can we predict the expected im- provement?

What will limit system perform- ance?

The validity of the prediction and alysis will, of course, depend upon e care with which we establish the ound rules and select our assump- ns. Frequently, we find that erroneous assumptions are buried in the se- ntics of our "short hand expres- ns" or equations. A major tech- logical advance which leads to an tstanding improvement in the para- eter which is normally recognized the weak link of a system may re- ire new concepts of analysis for per evaluation. In some cases we n leave out certain negligible fac- s or we can assume the non-varia- ity of others. A particular method analysis may be adequate for one tem, but completely inadequate for other — "the old order changeth lding place to new, lest one good stom should corrupt the world." In e face of major technological advances the petrification of ideas may lead to false predictions and deter advances at new frontiers.

Two questions are frequently asked these days — Should I put a Maser in my receiving system? How much will it improve system performance? The answer to the first question is intimately related to the specific technological advance which the Maser provides in a well defined area. The Maser is a low internal noise, microwave amplifier. If a system's performance is limited by R-F amplification noise, then a Maser may improve the system performance. The answer to the second question depends on the *degree* to which R-F amplification noise limits system performance. This is merely a re-statement of the well known fact that the strength of a chain is improved when we strengthen the weakest link. However, the improvement in this case will depend on the relative difference in strength between the weakest link and the next weakest, rather than on the improvement in the strength of the weakest.

The performance of most conventional microwave receiving systems is limited by system noise. The introduction of a low internal noise amplifier, such as a Maser, should therefore improve the performance of such systems. The Maser will strengthen this weak link by a factor of approximately one thousand over the conventional microwave systems. System performance, however, will definitely not improve by this amount. Few, if any, microwave receiving systems will realize the total improvement in system noise, reflected by the decrease in R-F amplification noise provided by a Maser.

In evaluating the improvement in system performance, produced by introducing a strengthening factor in the weak link, we must require that the new link not weaken other links in the system chain. Reduction in R-F Amplifier noise must not be at the expense of; bandwidth less than signal bandwidth, introduction of additional R-F losses, greater susceptibility to interference, poorer recovery after saturation, mechanical susceptibility to shock and vibration, gain stability, weight and volume considerations, and general reliability.

It is now generally recognized that Maser amplifiers, in completely contained closed liquid helium systems, can provide a major reduction in the system noise level in many microwave receiving systems without significant deterioration of other system characteristics.

The Maser has recently graduated from the status of a laboratory curiosity to that of a full fledged operational component. The remarkably short time required to transfer the Maser from time of concept to its present operational status has stimulated a careful review of conventional methods of system noise analysis.

The general opinion expressed by most microwave system engineers at the very outset of Maser development was that the principle application would be in the field of radio astronomy. Many radar system engineers set aside the Maser as a device whose low noise capability would make it a susceptible target for jamming by man-made interference. Though this may be true under some operational conditions, and "burning through" with high power tubes may be the operational rule, there is still much to be learned about electromagnetic propagation through space during times of negligible man-made interference. The advantages of having a high power tube on a particular frequency can be determined today at frequencies for which tubes are not available, by introducing a Maser within the system

Acknowledgment is due Jack Camp- ll, William From, Hays Penfield, and ter Rizzi, Research Group Directors Ewen Knight Corporation, for the mulating discussions which led to is presentation.

for research purposes. The estimated improvement in most radar systems would be comparable to introducing an increase of approximately 15 db in the average power level of the transmitter.

Radio astronomers were certainly among the first to grasp the significance of the technological advance represented by the Maser. This situation was more directly related to the radio astronomers' framework of reference, than to their proportionate degree of need for such a component in a microwave receiving system.

In some respects a radio astronomer's research program involves many of the complex ingredients shared by researchers in the field of high energy accelerators. A high energy accelerator research program was once likened to a man blindfolded in the middle of a large field populated with a random distribution of tennis balls. By groping in the darkness he may be able to find a tennis ball near his feet. He then throws the ball in some direction and, if he is lucky, the ball will pass through a window in a barn nearby (if the window happens to be open). The ball may then strike an animal standing within the barn and, if good fortune prevails, the ball will bounce back out through the window. If the researcher extends his hand in the proper direction he may be fortunate enough to catch the ball. His conclusion with regard to the type of animal in the barn is then based on his discernment when he smells the ball.

The radio astronomers goal can be simply defined as a complete spectro-analysis of the entire radio frequency spectrum for all directions in space. If he had undertaken this task with his present day radio equipment, at the time when the earth was first formed, he would still be far from the final accumulation of all the required data.

The startling discovery by Janske at the Bell Laboratories in 1932, that radio waves were coming to earth from outer space, led to the birth of this new scientific field of research. The observed radiation was completely unexpected and hence the investigation since that date has been based upon an analysis which is scientifically consistent with unexpected phenomena. When faced with a new phenomenon one frequently relates observations to a thermo-dynamic framework of reference.

The early days of radio astronomy (which are still with us) have been highlighted by discoveries, most of which were unanticipated. Predictions have been generally at a minimum.

2.0 SOME RADIOMETRIC FUNDAMENTALS

The radio astronomer in most instances utilizes a conventional radio receiver as his tool of observation. The receiver is usually referred to as a radiometer. Modification of the receiver, if any, is frequently minor. The principle difference is usually found in the radio astronomer's conceptual approach to the equipment.

The radio astronomer looks upon a receiver as a temperature measuring device, because the signals which he receives, and did not originally anticipate, are of a noise-like character, and hence by simple thermodynamic consideration can be related to the equivalent noise produced by a black body at a well defined temperature.

The fundamental ingredients of any receiver consist of an antenna, an amplifier, a detector, and an indicator. From a thermodynamic standpoint the antenna may be considered as a device which transports its radiation resistance at the input terminals of the receiver into a thermal reservoir contained within the volume of space "observed" by the antenna and determined by its directive characteristics. If we then assume that the observed medium is a composite black body reservoir at some temperature T, then the temperature of the radiation resistance of the antenna will come into equilibrium with the temperature of this reservoir. The amplifier portion of the receiver then amplifies the power presented to its input terminals by the radiation resistance. This power level is the well known Johnson noise power KTB where K is Boltzmann's constant, T is the equivalent temperature of the radiation resistance and B the predetection bandwidth of the amplifying device. The power input to the amplifier is then equivalent to the power output of a resistor matched to the receiver input, and immersed in a thermal reservoir at temperature T. Since this power level is directly proportional to the temperature of the reservoir the radio astronomer refers to the signal input in temperature units (of degrees Kelvin).

In the Rayleigh-Jeans approximation for the brightness of Planck radiation, the brightness per unit cycl
is inversely proportional to the squar
of the wavelength, whereas Johnso
noise power is independent of fre
quency and dependent only upon tem
perature. The thermodynamic bal
ance of the two sources of power
obtained, in a receiving systen
through the wavelength characteristi
of the average antenna cross sectio
When performing the integration c
the product of brightness per un
wavelength and antenna cross sectio
over the bandwidth of the receive
and the solid angle of the antenn
aperture, the wavelength dependen
terms cancel. Hence an antenn
totally immersed in a black body a
temperature T will contribute a con
stant power output at its terminal
independent of frequency.

Since radio astronomers measur
signal strength in temperature unit
(degree Kelvin), it logically follow
that they then express the noise con
tributed by the R-F circuits of thei
receiver, in equivalent temperatur
units.

In summary, the logic goes as fol
lows: The power incident upon th
antenna aperture within the ban
width of the receiving system produce
a thermal bath for the radiation re
sistance of the antenna, at the tem
perature of the "composite equiva
lent" black body viewed by the an
tenna. This antenna temperature
then transmitted to the amplifier vi
the Johnson noise mechanism, whe
it is amplified in the presence of th
noise power attributable to the man
made circuitry. This receiver nois
power level is described in terms o
an *equivalent receiver noise tempera
ture.*

Recently there has been consider
able controversy among microwav
engineers concerning the usage of ce
tain "noise terminology." The intro
duction of Masers and other low nois
solid state amplifiers has provided
major stimulus for such controvers
Admittedly, there has been some mi
use of certain terms. However, th
major differences of opinion are som
what equivalent to deciding whethe
linear dimensions should be expresse
in meters or millimeters. The conve
sion from meters to millimeters
admittedly a little less complex tha
the conversion of "noise figure"
"effective noise temperature," sinc
there is no constant multiplying fact
relating the two. System engineers a
generally divided into two groups d

nding upon their degree of familiarity with either concept. Both concepts equally acceptable and each has its rit depending upon the applica-n.

The advent of the Maser has unestionably contributed to a more neral usage of the "system noise nperature" concept. As we now apach theoretical perfection, in the mination of R-F amplifier noise, our rch for the new weak link in such tems lends itself to the usage of ise temperature" as opposed to ise figure" terminology.

Fortunately, in this case, it appears t terminology will follow the simcity of description.

Frequently, too many definitions l new terms tend to cloud the simcity of an explanation and give rise a clique of experts surrounded by impenetrable wall of semantics.

To assist in the discussion to follow, basic concepts of noise figure and ise temperature are presented for erence purposes.

The figure of merit or noise figure) of a receiving system, amplifier any other signal path network, is ined simply as the power ratio:

$$F = \frac{\left(\frac{\text{Signal}}{\text{Noise}}\right)\text{Input}}{\left(\frac{\text{Signal}}{\text{Noise}}\right)\text{Output}} \qquad (1)$$

By definition, the smallest value of is unity or zero db. If F were less n unity or if it were expressed in gative decibels, we would imply t the device was capable of reducing noise level at its input terminals thout reducing the signal level. Such vices are as yet unknown. A noises device provides a unity noise fige, that is to say, it does not contrib to the "effective input noise wer."

By definition, the input noise power r cycle in Equation 1 is equivalent the Johnson noise power per cycle ovided by a resistor matched to the out terminals of the device at a nperature of 290°K and hence is ual to KT_o where;

K = Boltzmann's constant

$T_o = 290°K$

This quantity is frequently referred as the "theoretical ambient noise wer per cycle."

Equation 1 may be applied to any gnal path network or system.

If we define P_N as the effective ise power of a network, referred to its input terminals, then if the device has a gain G, Equation 1 takes the form:

$$F = \frac{\frac{S}{KT_o}}{\frac{GS}{GKT_o + GP_N}} = 1 + \frac{P_N}{KT_o} \qquad (2)$$

or:

$$P_N = (F - 1)\, KT_o \qquad (3)$$

Expressing P_N in terms of Johnson noise power per cycle we may write P_N in the form;

$$P_N = KT_e \qquad (4)$$

from (3);

$$T_e = (F - 1)\ T_o \qquad (5)$$

T_e is defined as the "effective input noise temperature" of the network or simply, the network "noise temperature."

If the noise figure of a system or device is unity or zero db, then its noise temperature is 0°K.

If a network of noise figure F_1 and gain G_1 is cascaded with a network of noise figure F_2 and gain G_2, it can be shown that the noise figure of the combination $F_{(1+2)}$ is given by the expression:

$$F_{(1+2)} = F_{(1)} + \frac{F_2 - 1}{G_{(1)}} \qquad (6)$$

which can be written in the form:

$$(F_{(1+2)} - 1)\ T_o = (F_{(1)} - 1)\ T_o + \frac{(F_{(2)} - 1)\ T_o}{G_{(1)}} \qquad (7)$$

From Equation 5 we see that:

$$T_{e(1+2)} = T_{e(1)} + \frac{T_{e(2)}}{G_{(1)}} \qquad (8)$$

Or, the noise temperature of two cascaded networks is equal to the noise temperature of the first plus the noise temperature of the second "reduced" by the gain of the first network. We could have deduced Equation 7 intuitively by considering that the noise power and hence noise temperature contribution of the first stage would be enhanced by the gain of the first stage over the second. Equation 6 could then easily be derived from Equation 8, by the definition of noise figure.

From the definition of F, it is apparent that the noise figure of a transmission line of loss L is equal to L and hence its noise temperature is equal to $(L - 1)\ T_o$. This value should not be confused with the re-radiated temperature of a transmission line of loss L which is given by the expression:

$$\left(1 - \frac{1}{L}\right) T_o \qquad (9)$$

If we cascade a transmission line of loss L with an amplifier of noise figure F the noise figure of the combination in cascade is FL. The effective noise temperature of the combination is therefore, $(FL - 1)\ T_o$.

Consideration of the noise figure of a Maser leads one directly to the present controversy with regard to the usage of *noise temperature* as opposed to *noise figure.* From Equation 2 and 4 we see that the noise figure of a system is related to the noise temperature by the simple expression;

$$F = \frac{T_o + T_e}{T_o} = \frac{290 + T_e}{290} \qquad (10)$$

For Masers, T_e obtains a value of less than 5°. Since noise figures are usually expressed in db, one must insert the value of T_e in Equation 10 and then compute the logarithm of the resulting power ratio. For small values of T_e it would appear that the mere statement of T_e would be a more significant criterion of the figure of merit of the circuit.

The following table should assist in clarifying this point.

TABLE I

$$F = 1 + \frac{T_e}{290}$$

T_N °K	F	F (db)
1.0	1.0034	0.015
2.0	1.0069	0.030
3.0	1.0103	0.045
4.0	1.0138	0.059
5.0	1.0172	0.074
6.0	1.0207	0.089
7.0	1.0241	0.103
8.0	1.0276	0.118
9.0	1.0310	0.132
10.0	1.0345	0.147
100.0	1.3450	1.287
200.0	1.6900	2.279
300.0	2.0350	3.085

3.0 A THERMODYNAMIC APPROACH TO SYSTEM ANALYSIS

Many microwave research engineers today prefer the usage of the noise temperature concept as opposed to noise figure for the simple reason that noise figure is usually measured at the input terminals of the receiver and thereby ignores many factors which may be major contributors to the overall system noise level.

The noise figure concept is *intimately related to a precise method for its measurement.* In systems which are limited by receiver noise contributions, from circuitry *following* the receiver input, the measurement of

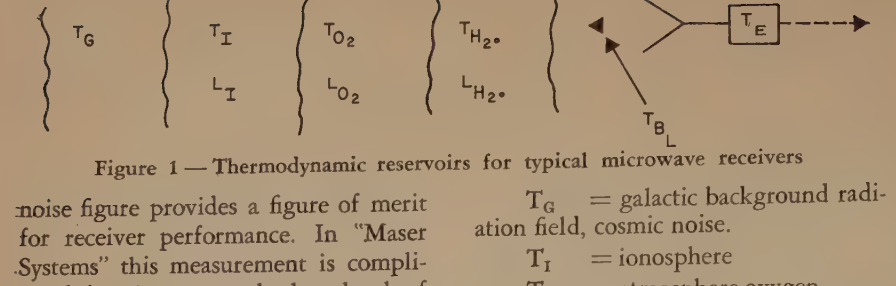


Figure 1 — Thermodynamic reservoirs for typical microwave receivers

noise figure provides a figure of merit for receiver performance. In "Maser Systems" this measurement is complicated by the extremely low level of noise to be measured. The accuracy of the measurement is strongly influenced by the degree to which R-F component parameters of the test equipment are known. A serious attack on this problem requires infinite care in the precise measurement of the specific test equipment. Even with greatest care, the errors in such measurement invariably indicate that the noise figure of the test equipment is greater than that of the Maser.

At this point such measurements on Maser amplifiers may be considered quite academic since the figure of merit of the system will undoubtedly be determined by other factors. Parametric amplifiers should not be treated so abruptly. Their noise temperature contribution will be somewhat higher than Masers and may, in many cases, remain the weak link in the system. One should consider these devices with great caution however, since the mode of operation in each specific application requires individual analysis.

One might conclude from the foregoing remarks concerning maser systems that noise is not the weak link in such systems. Quite to the contrary, such systems may be limited by noise; however, the principle contribution will be made in the signal path forward of the maser. This signal path includes components whose noise contribution is more effectively measured by techniques other than those usually employed in the measurement of noise figure. Consider the system shown in Fig. 1.

The diagram crudely depicts the thermodynamic situation which is realized when a receiving antenna is pointed into space. For the sake of simplicity let us assume that the forward lobes of the antenna intercept the four thermal reservoirs as shown and that the equivalent black body temperature of each reservoir is T_G, T_I, T_{O_2}, and T_{H_2O}.

The equivalent black body temperatures, as shown, refer respectively to the following thermal reservoirs:

T_G = galactic background radiation field, cosmic noise.

T_I = ionosphere

T_{O_2} = atmosphere oxygen

T_{H_2O} = atmospheric water vapor

Associated with the latter three are their respective attenuations or losses L_I, L_{O_2}, and L_{H_2O}.

In addition to these thermal reservoirs, the antenna also views the earth ambient as a thermal reservoir through its back lobes and primary pattern spillover, which produces a temperature contribution T_{BL}.

All passive R-F hardware losses forward of the first active circuit, including antenna losses, are shown as L. The effective ambient temperature of these losses is shown as T_L.

The effective noise temperature of all active circuits is shown as T_e.

The *total effective system noise temperature* is determined by all of the foregoing parameters. Each one can be further sub-divided and frequently is, in the search for each system's weakest link.

In general, the *total effective system noise temperature* may be expressed as the sum of three terms:

a) Effective space noise temperature
b) Effective passive hardware noise temperature
c) Effective R-F amplification noise temperature

Low noise system development is now directed toward the goal of reducing all three noise contributions. The first can be reduced only by careful selection of the operating frequency and the program of observation. The latter two are the subject of advanced research in component development.

SPACE TERM:

The "space term" contribution depends on the physical position of the signal source, insofar as loss contributions diminish signal intensity and thereby amplify the reradiated temperature of losses physically located between the signal source and the receiver.

For a signal source located beyond the earth's ionosphere, the effective noise temperature contribution space term is given by the expressio

$$T_G + (L_I - 1)\, T_I + (L_{O_2} - 1)\, T_{O_2} + (L_{H_2O} - 1)\, T_{H_2O}\, L_I\, L_{O_2} \quad (1$$

It should be noted that the sig source itself may contribute to syst noise if it is of a noise like charact Admittedly this is a fine point, sin in general we consider the avera power of such signals separately. Ho ever, in some rather important app cations we frequently wish to det mine the existence of small variatic in the spectral distribution of su sources. In some cases the noise ch acter of the source may limit detec bility and a larger antenna aperture lower R-F amplifier noise will not i prove the system's performance, detection of interstellar deuterium absorption techniques.

Investigation of the various terms Equation (11) leads to the followi general analysis for frequencies abo 250 Mc.

Galactic Background Radiati Field, (T_G) is generally predomina over the range 250 Mc to 1000 M This term is both frequency and pp tion dependent.

Ionospheric Effects $(L_I - 1)\, T_I$ essentially negligible above 250 M from a noise contribution standpoi however, scintillation effects due turbulence and wave phenomena m produce noticeable deterioration in s tem performance in the vicinity 250 Mc. This term is predominant VHF and lower frequencies.

Atmospheric Oxygen $(L_{O_2} - 1$ T_{O_2} L_I and *Atmospheric Water V por* $(L_{H_2O} - 1)\, T_{H_2O}\, L_I\, L_O$ become predominant above 10 k where the composite effective radi tion temperature of these gases b comes approximately 10°K and the after rises quite sharply with incre ing frequency. The attenuation a resultant re-radiation in the two ga is associated with the existence of e treme infrared absorption bands. T water vapor absorption band locat at 1.2 cm is produced as a consequen of the electric dipole moment water. The oxygen band located at cm, is associated with the magne dipole moment of the oxygen mo cule. The attenuation in each (at a given frequency) is proportio to the partial pressure and hence can expect considerable modificati of the spectral structure of the co posite attenuation, as a function

itude, due to the non-uniform distribution of the two gases along a rtical path. This measurement ould provide an interesting challenge space-borne radiometric equipent.

A composite profile of space temrature is shown in Fig. 2. The galacbackground radiation field has been otted along with the composite radion temperature of the atmospheric ses. It is of interest to note that a pace window" exists in the spectrum tween 1,000 Mc and 10,000 Mc at ich the full potential of maser sysns could be realized, *if* such systems noise limited in performance by F amplification noise *only.*

F Hardware Term:

$T_{BL} + (L - 1) T_L L_I L_{O_2} L_{H_2O}$

The R-F hardware term consists of ective noise temperature contribuns produced by the passive hardre forward of the first active circuit. conventional radiometric systems first "active" circuit is considered be the R-F amplifier or first crystal nverter. In a maser system, the first ive circuit is the maser itself. Anna losses, plumbing losses, switch ses, duplexer losses, etc., fall into s category.

In Fig. 1 all of these losses are nmed into a composite total loss of ue L. The effective ambient temrature of these losses in indicated T_L.

In addition to the effective noise ntribution produced by these losses, other hardware term should be inded which arises as a consequence the antenna's inefficiency in directits entire pattern into the forward ection. This contribution to the ective system noise temperature is own in Fig. 1 as T_{B_L} and is proced by spillover of the primary patn of the feed system. The feed will ntribute a temperature T_{B_L} to the tem as a consequence of back lobes lobes which, in general, intercept earth as a thermal reservoir.

In the frequency range, 1000 Mc 10,000 Mc, this term may well inde a maser system's weak link from noise contribution standpoint.

oise Temperature of "Active" rcuits — $T_e \; L_I \; L_{O_2} \; L_{H_2O} \; L$

The last term in the expression *the total effective noise temrature of the system* is the contribun of active circuits. The use of the m "active" may be somewhat out of ntext since the maser like a conrter is a passive device, however,

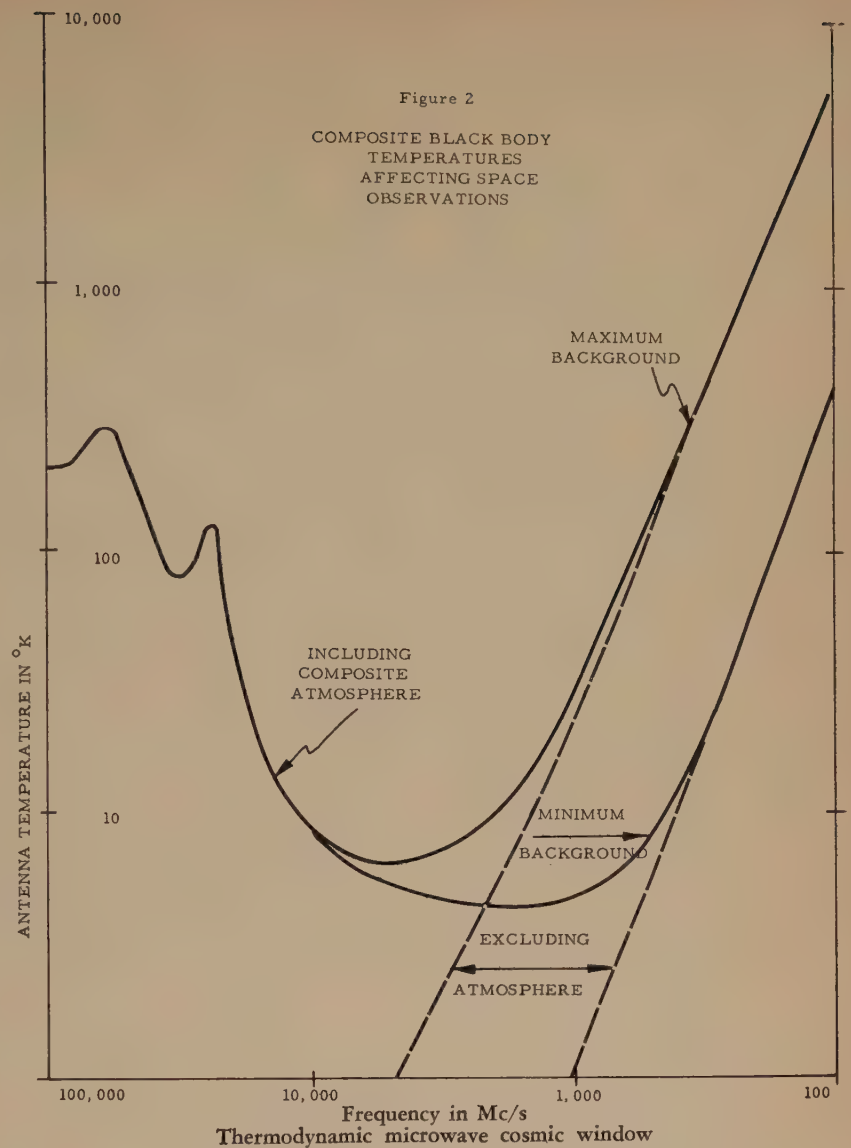


Figure 2

COMPOSITE BLACK BODY TEMPERATURES AFFECTING SPACE OBSERVATIONS

Thermodynamic microwave cosmic window

both are powered by an external oscillator. The term is used here to define that portion of the receiving system usually referred to as "the receiver" and includes all signal networks from the input (converter or maser) to and including the output indicator. In non-maser microwave receiving systems this portion of the system usually provides the greatest contribution to the *effective system noise temperature.* The conventional figure of merit or noise figure of such systems usually refers specifically to the measurement of this portion of the overall effective system noise. Loss contributions are merely added (in db) to the measured noise figure of the receiver to determine the overall noise figure in the normal usage of the term. Such plumbing losses are usually measured by familiar loss-measurement techniques as opposed to an actual noise figure measurement of such losses.

As indicated previously the noise figure or noise temperature of this portion of a "maser system" is strictly academic since:

a) Its contribution to system noise is quite negligible.

b) The difficulty encountered in making a *precise* measurement leads one to new concepts of noise figure measurement, far beyond the scope of conventional techniques.

Composite Expression

$$T_{system} = T_G + (L_I - 1) T_I + (L_{O_2} - 1) T_{O_2} L_I + (L_{H_2O} - 1) T_{H_2O} L_I L_{O_2} + T_{BL} + (L-1) T_L L_I L_{O_2} L_{H_2O} + T_e L_I L_{O_2} L_{H_2O} L$$

If we assume:

$$T_I = T_{O_2} = T_{H_2O} = T_L T_O$$

and let:

$$L_I L_{O_2} L_{H_2O} L = L_O$$

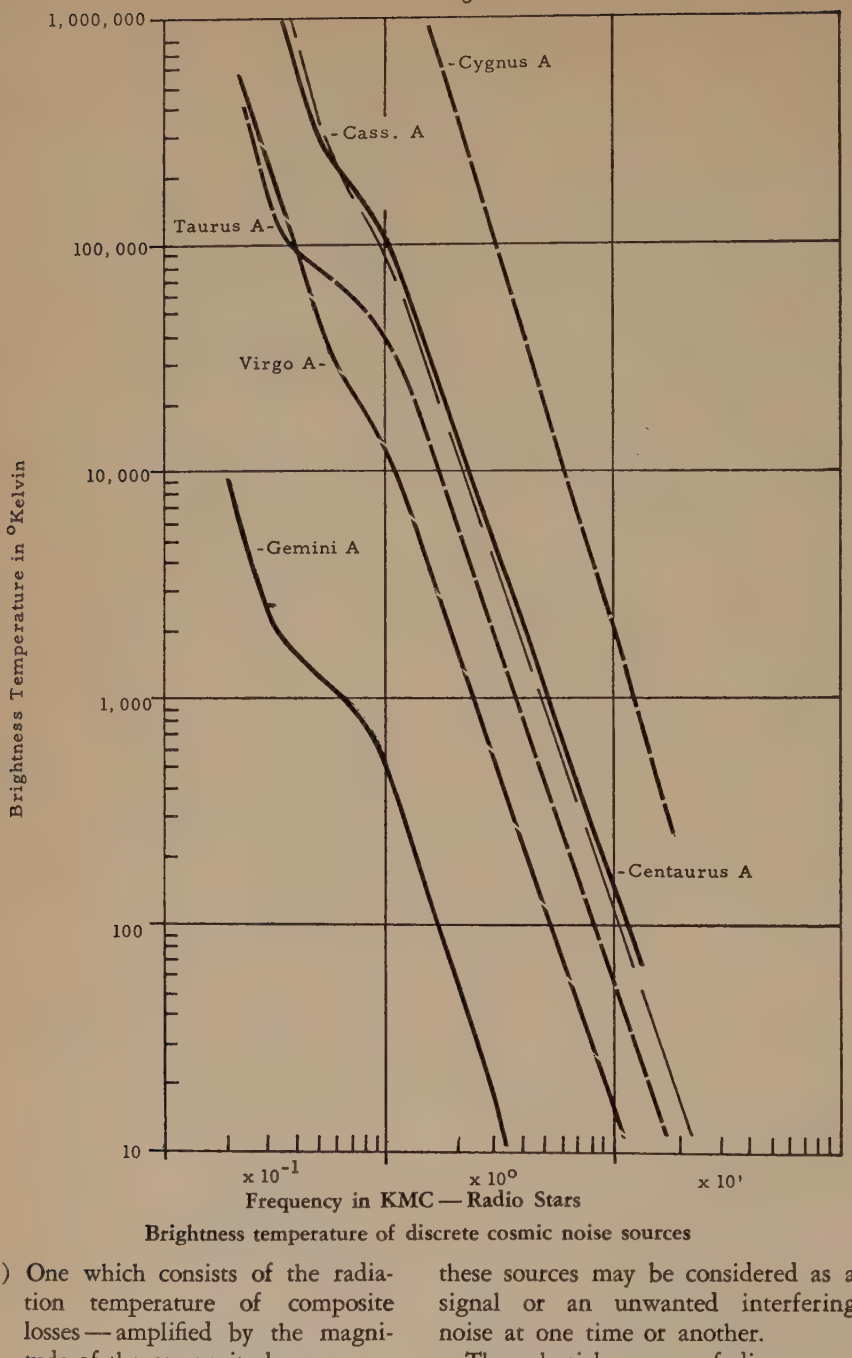
Then:

$$T_{system} = [T_G + T_{BL}] + [(L_O - 1) T_O] + [T_e L_O]$$

or the total effective system noise temperature consists of three terms:

a) One which consists of temperature contributions from sources outside the signal path.

Figure 3



Brightness temperature of discrete cosmic noise sources

b) One which consists of the radiation temperature of composite losses — amplified by the magnitude of the composite loss.

c) One which consists of the effective temperature of active circuits — amplified by the magnitude of the composite loss forward of these circuits.

Other Contributions to System Noise:

In addition to the system noise sources shown in Fig. 1 there are *discrete external sources* of noise which may produce limitations in system performance because of their noise power contribution. These discrete external sources may be roughly divided into two types.

a) Celestial

b) Man-Made

Depending on the occasion, or the specific program of reception, each of these sources may be considered as a signal or an unwanted interfering noise at one time or another.

The celestial sources of discrete radiation such as the sun, moon, planets, "radio stars," planetary nebulae, etc., are fairly well defined with regard to their intensity (Fig. 3) and position in space and hence reasonable predictions can be made with regard to their contribution in a specific system application.

Man made "noise" is a naughty phrase among radio astronomers, since this particular noise source is increasing its average power level over the entire spectrum and in a few decades may obsolete the need of a discussion such as presented in this paper.

Summary and Conclusions

The maser and "similar" low noise solid state amplifiers constitute a startling advance in microwave receiving system performance. Once the weakest link in the system, R-F amplification noise is now the strongest. The resultant improvement in system performance will require a careful review of each system.

In General:

Below 1000 Mc receiving systems will be limited by the galactic background radiation field.

Above 10,000 Mc receiving systems will be limited by absorption in the atmospheric gases of water vapor and oxygen.

In the frequency range 1000 Mc to 10,000 Mc maser receiving systems at present will probably be noise limited by R-F hardware forward of the maser.

The noise figure concept, though very useful for conventional systems, is of academic interest when discussing maser amplifiers as isolated amplifiers. The use of the "effective noise temperature" concept has greater appeal for maser system analysis since the major sources which contribute to the *"over all system noise figure"* in many instances can not be measured by standard noise figure techniques and are invariably measured by radiometric techniques, directly calibrated in equivalent noise temperature units, °K.

There is no solution readily available to answer the question, "what will a maser do for my system"? A detailed analysis of each specific system will be required. The best test equipment will be the maser itself in the precise measurement of many of the system parameters currently considered negligible in conventional systems.

New techniques to improve the R-F hardware forward of the maser are the present order of the day. Better circulators, switches, TR devices, feed systems, etc., point for solution to advances yet to come through solid state material research.

With the availability of closed cycle liquid helium systems, *now a reality*, the maser has graduated from the laboratory frontier to an operational status. One can realize its full potential with a system concept that encompasses the entire environment of the receiving system.

What will ultimately limit the perfect systems sensitivity? Time! Time of observation and the time dependence of "space term" losses. Even if they were uniform in time, their inescapable variation as a function of angular elevation ties this term back to *time* of observation.

RINCIPLES OF MICROWAVE INTERACTIONS VITH IONIZED MEDIA . . . . . .

. F. WHITMER SYLVANIA ELECTRIC PRODUCTS CO. MICROWAVE PHYSICS LABORATORY

PART II

ELECTRON-CYCLOTRON RESONANCE

Introduction

'art I of this article, which appeared he preceding issue of this journal, lained the concept of plasma reson- e and its relation to electromagnetic e propagation. The purpose of this cle is to discuss the propagation racteristics of such a wave in the rence of an ionized medium and a magnetic field. It will be shown the addition of a dc magnetic field greatly affect the propagation char- ristics of a wave and thereby ex- l the number of applications in ch a plasma may be used. This dis- ion is also applicable to ionos- ric propagation when the effects he earth's magnetic field are of im- tance.

Electron Cyclotron Frequency

et us consider an electron moving h a velocity v in the presence of a form dc magnetic field of value . |. The equation of motion of the tron is then

$$m\frac{dv}{dt} = e\,(v \times B_o) \tag{1}$$

ere MKS units are used and the no- ion is the same as was used in Part e is negative). From the right-hand e of Eq. (1) it can be seen that the tron's component of velocity which n the direction of B_o, denoted by is unchanged by B_o; that is, since $\times B_o = o$, $\frac{dv_{\parallel}}{dt} = o$, and $v_{\parallel}$ constant. This constant is, of course, $v_{\parallel}$ at the time $t = o$. Therefore, electron moves at a constant veloc- in the direction of the magnetic l lines. The remaining part of Eq.) is

$$m\frac{dv_{\perp}}{dt} = e\,(v_{\perp} \times B_o) \tag{2}$$

ere $v_{\perp}$ is the component of the tron velocity which is perpendicular to B_o. The motion described by Eq. (2) corresponds to an angular motion about B_o and, therefore, Eq. (2) can be written as

$$\frac{dv_{\perp}}{dt} = \omega_c \times v_{\perp} \tag{3}$$

where

$$\omega_c = -\frac{e}{m} B_o. \tag{4}$$

ω_c is called the electron cyclotron frequency. It can be seen that the electron motion consists of a circular motion around the magnetic field lines with a uniform translation along the magnetic field lines. Eq. (4) can be written as

$$f_c/B_o = 2.799 \text{ Mc/gauss} \tag{5}$$

for electrons, where $\omega_c = 2\pi f_c$.

III. The Electromagnetic Wave

As in Part I, let us assume that a uniform plasma completely fills all space and, in addition, let us assume that a uniform dc magnetic field is present throughout the plasma. A wave propagating in this medium must satisfy Maxwell's Equations

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{6}$$

$$\nabla \times H = \frac{\partial D}{\partial t} + J \tag{7}$$

where

$$\frac{\partial (en)}{\partial t} + \nabla \cdot J = o. \tag{8}$$

The motion of the electrons can be determined from the force equation

$$n\,m\frac{dv}{dt} + n\,m\,\nu\,v = n\,e(E + v \times B_o) \tag{9}$$

as in Eq. (I—22). The term $(v \times B)$ has been neglected, compared with $E + v \times B_o$ as in Part I. The procedure for solving Eqs. (6)-(9) is similar to that followed in Part I; that is, J is obtained as a constant times E from Eq. (9). Then an effective dielectric constant can be derived from Eq. (7), from which the propagation characteristics can be determined. This procedure is, however, somewhat complicated due to the presence of the dc magnetic field. In the case $B_o = o$, Eq. (I—11) shows that an electric field in one direction, for example the x-direction, produces a current density in, and only in, the x-direction. However, when $B_o \neq o$ it has been shown that an electron starting in a given direction may change its direction due to the effect of the dc magnetic field. In other words, an electric field in the x-direction may produce currents in the x, y, and z-directions. This property of a plasma in a magnetic field results in the medium's being anisotropic; that is, the plasma exhibits different properties along axes in different directions. Mathematically this is equivalent to saying that a tensor relationship exists between J and E; consequently, the effective dielectric constant is also a tensor.

The mathematical problem is somewhat simplified by assuming that B_o is in the direction of one of the coordinate axes, say the z-direction, of a rectangular coordinate system. Following the procedure just outlined, the effective dielectric tensor can be represented as

$$\epsilon' = \begin{vmatrix} \epsilon_{11} & i\epsilon_{12} & o \\ -i\epsilon_{12} & \epsilon_{11} & o \\ o & o & \epsilon_{33} \end{vmatrix} \epsilon \tag{10}$$

where the elements of the matrix are given in the Appendix. It can be shown that for $B_o = o$ (that is, $\omega_c = o$), $\epsilon_{11} = \epsilon_{33}$ and $\epsilon_{12} = o$ and ϵ' reduces to the result given in Eq. (I-24). Consequently, it is apparent that the anisotropic nature of the medium is due to the effect of the dc magnetic field. Before analyzing the properties of ϵ' in detail, a transformation of the field variables will be made which simplifies the discussion.

Let us transform the field variables E_x and E_y to $E_\pm$, where

$$E_\pm = E_x \pm iE_y. \qquad (11)$$

This implies that a transformation has been made from linear to circular polarization. Since multiplication by $(+i)$ corresponds to a right-hand rotation from x to y around z, E_+ represents a right circularly polarized wave and E_- a left circularly polarized wave. The effective dielectric constant for these two waves, called $\epsilon'_\pm = (\epsilon_{11} \pm \epsilon_{12})\epsilon$, is

$$\epsilon'_\pm = \left[1 - \frac{\omega_p^2(\omega \mp \omega_c) - i\nu}{\omega\,[(\omega \mp \omega_c)^2 + \nu^2]}\right]\epsilon \qquad (12)$$

which is different, depending upon the direction of circular polarization of the wave. It can be seen that $\mathrm{Re}(\epsilon'_+) > \epsilon$ for $\omega < \omega_c$, whereas ϵ' was always less than ϵ for the case $B_o = 0$. Furthermore, since the imaginary part of ϵ' represents a dissipative property of the medium, the medium has a resonance-type loss at $\omega = \omega_c$. This resonance characteristic is known as electron-cyclotron resonance and may be understood on the basis of a rather simple argument. An electron moving in the y-direction which is acted on by a magnetic field in the z-direction experiences a force in the $-$x-direction. Viewed in the z-direction this electron will rotate about a magnetic field line in a clockwise direction. But ϵ'_+ is a property of the medium for a circularly polarized wave which rotates in a clockwise direction. Therefore, when $\omega = \omega_c$ the electron and the wave are rotating in the same direction at the same frequency, and a resonance condition occurs. In this manner a large amount of electromagnetic energy can be transferred to the electrons when $\omega = \omega_c$. This partially accounts for the ease with which a gas may be ionized by a microwave signal when $\omega = \omega_c$. It is easily seen from Eq. (12) that such resonance effects do not occur for the left circularly polarized wave. This is to be expected since the electron and wave are rotating in opposite directions in this case.

IV. Propagation in an Anisotropic Medium.

The discussion of propagation in the presence of an anisotropic ionized medium is, of course, complicated by the fact that the effective dielectric constant is a tensor. The propagation constant, in the absence of a dc magnetic field, was given by the solution of Eq. (I-19), which is rewritten below,

$$\gamma^2 + \mu\,\epsilon'\,\omega^2 = 0. \qquad (13)$$

In the case of an anisotropic medium the propagation constant can be obtained by writing the wave equation, which involves ϵ', in component form. This results in a system of three homogeneous linear equations, and for a solution of these equations to exist the determinant of the coefficients in these equations must vanish. For the general case of propagation of the form $e^{\gamma \cdot r}$ where $\gamma = \hat{x}_o\,\gamma_x + \hat{y}_o\,\gamma_y + \hat{z}_o\,\gamma_z$ the determinant can be written as

$$|\,\gamma^2\,\delta_{ij} - \gamma_i\,\gamma_j + \omega^2\,\mu\,\epsilon'_{ij}\,| = 0. \qquad (14)$$

$\hat{x}_o$, $\hat{y}_o$, and $\hat{z}_o$ are unit vectors in the directions of the coordinate axes, $\gamma^2 = \gamma_x^2 + \gamma_y^2 + \gamma_z^2$ and $\delta_{ij} = 0$ for $i \neq j$ and $\delta_{ij} = 1$ for $i = j$. In this notation i and j represent x, y, and z so that the xy element, for example, of the determinant is obtained by setting $i = x$ and $j = y$. The solutions of this determinant will be discussed for two special cases:

Case I: Propagation in the direction of the dc magnetic field.

For this case the solution of the determinant shown in Eq. (14) yields

$$\gamma^2_\pm = -\mu\,\epsilon'_\pm\,\omega^2 \qquad (15)$$

where $\gamma_\pm$ indicates a propagation constant for a right and left circularly polarized wave. Furthermore, it can be shown that $E_z = 0$; that is, these waves are transverse waves. The solution of Eq. (15), using Eq. (12), can be written as

$$\gamma_\pm = \alpha_\pm + i\beta_\pm \qquad (16)$$

where $\alpha_\pm$ and $\beta_\pm$ are real and are given in the Appendix.

For the case $\nu = 0$, $\alpha_\pm = 0$ over most of the spectrum, and

$$\beta_\pm = \frac{\omega}{c}\left[1 - \frac{\omega_p^2}{\omega\,(\omega \mp \omega_c)}\right]^{\frac{1}{2}}. \qquad (17)$$

For the right circularly polarized wave propagation occurs (β_+ is real) for all values of ω for $\omega < \omega_c$ and also occurs when $\omega > \omega_+$. For the left circularly polarized wave, propagation oc

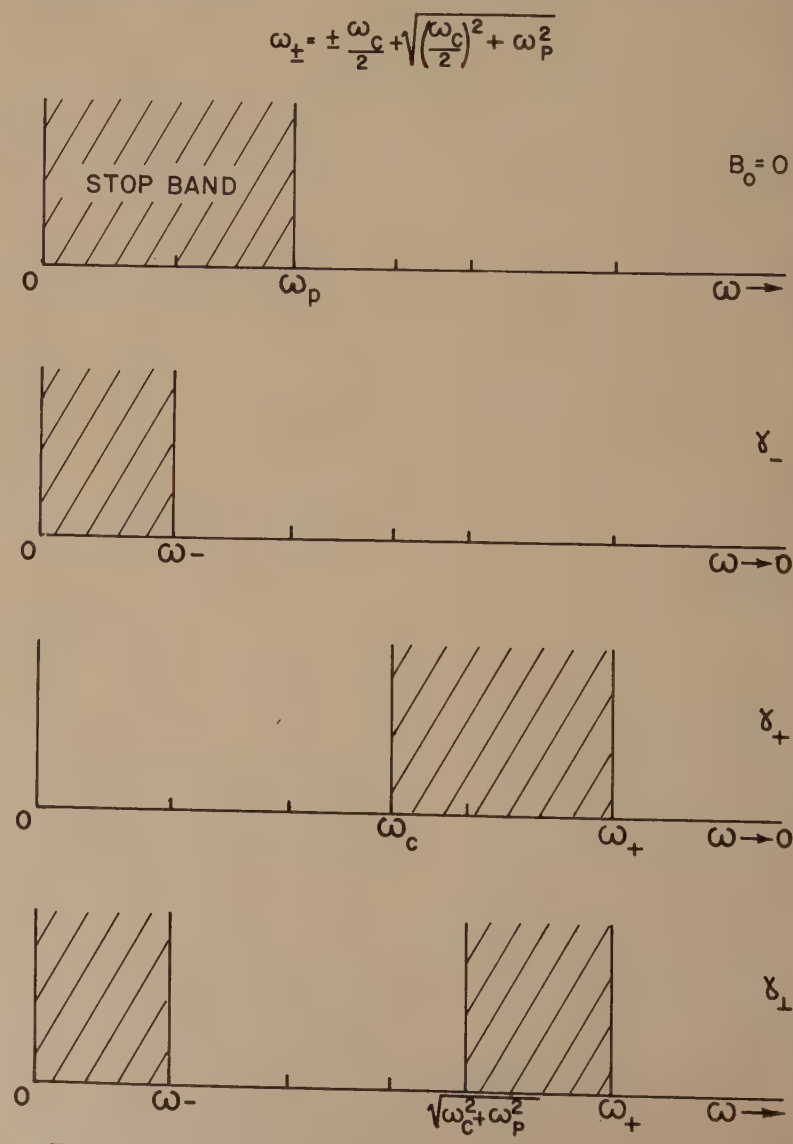


Figure II - 1 — Filter characteristics of the medium for the various waves.

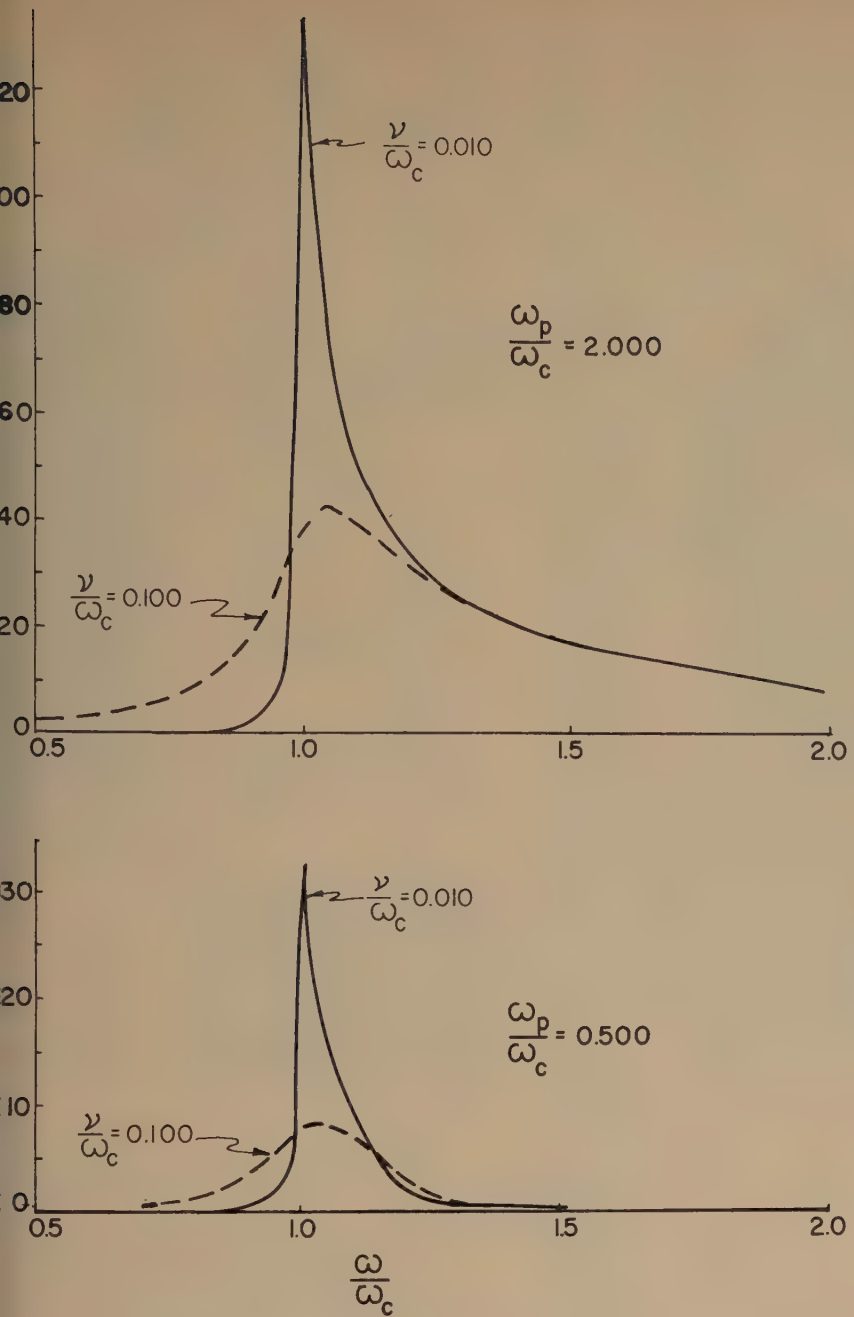


Figure II - 2 — Attenuation characteristics of $\delta+$.

only for $\omega > \omega_-$. In other words, medium acts as a high pass filter, lar to the case of $B_0 = 0$, for the circularly polarized wave with a band when $\omega < \omega_-$. The medium like a stop band filter for the right ularly polarized wave where the band exists in the region $\omega_c < \omega$ $_+$. $\omega_\pm$ is defined by

$$= \pm \frac{\omega_c}{2} + \sqrt{\left(\frac{\omega_c}{2}\right)^2 + \omega_p^2} \qquad (18)$$

effect of ν is simply to smooth the sition between the pass bands and stop band.

e II: Propagation perpendicular to ne direction of the dc magnetic eld.

The solution of the determinant shown in Eq. (14) with $\gamma = \gamma_\perp$ yields

$$\gamma_\perp^2 = -\mu\,\omega^2 \frac{2\,\varepsilon'_+\,\varepsilon'_-}{\varepsilon'_+ + \varepsilon'_-} \qquad (19)$$

and $E_z = 0$, or

$$\gamma_\perp = \gamma_B \qquad (20)$$

and $E_x = E_y = 0$, and $E_z \neq 0$. The latter solution, called γ_B, corresponds to a wave with an E-field only in the direction of the dc magnetic field. γ_B is the same as γ for $B_0 = 0$ since E_z imparts a velocity to the electrons which is in the direction of B_0 and, therefore, the electrons are not affected by B_0. The solution of Eq. (19) in terms of $\alpha_\perp$ and $\beta_\perp$ is easily derived, but is quite complicated, and will not be given here. An indication of the propagation phenomena can again be obtained by examining the case for $\nu = 0$. For this case

$$\gamma_\perp = i\frac{\omega}{c}\sqrt{1 - \frac{\omega_p^2(\omega_p^2 - \omega^2)}{\omega^2(\omega_p^2 - \omega^2 + \omega_c^2)}} \qquad (21)$$

and the medium acts as filter with stop bands in the regions $0 < \omega < \omega_-$ and $\sqrt{\omega_c^2 + \omega_p^2} < \omega < \omega_+$.

A summary of the characteristics of propagation through an anisotropic ionized medium is shown diagrammatically in Fig. 1 for the case $\nu = 0$. When $B_0 = 0$, that is the case discussed in Part I, the medium acts as a high pass filter with a cutoff frequency at $\omega = \omega_p$. The effects are the same for $B_0 \neq 0$ if the rf E-field is only in the direction of B_0. This is illustrated in Fig. 1(a). In Fig. 1(b) the case of a left-hand circularly polarized wave propagating in the direction of B_0 is illustrated. It is seen that the medium is again a high pass filter but with a cutoff at $\omega = \omega_-$; that is, the dc magnetic field in effect has reduced the value of ω_p. In Fig. 1(c) it can be seen that for the right-hand circularly polarized wave a stop band is introduced. The dc magnetic field has moved the lower end of the stop band from $\omega = 0$ (when $B_0 = 0$) to $\omega = \omega_c$ and the upper end from $\omega = \omega_p$ (when $B_0 = 0$) to $\omega = \omega_+$. The most interesting feature of this wave is that all frequencies below $\omega = \omega_c$ will propagate through the medium regardless of the value of ω_p. (Whereas, for the case $B_0 = 0$, the electrons excluded frequencies below ω_p from propagating.) The characteristics of a wave propagating perpendicular to the direction of the dc magnetic field are shown in Fig. 1(d). As can be seen, the effects of B_0 are to insert a pass band in the region which was normally cut off for the case of $B_0 = 0$. At the same time, the upper end of the stop band has been raised above what it was for the case $B_0 = 0$.

The effects of ν, the electron-neutral particle collision frequency, are not easy to discuss in detail. In general, for small values of ν, the effects of ν are simply to smooth out the transitions between the stop and pass bands and to shift slightly the frequencies at which the bands occur. Of course, the stop bands have a finite attenuation when ν is considered. Typical curves of attenuation and phase for the

right-hand circularly polarized wave propagating in the direction of the dc magnetic field are shown in Figs. 2 and 3. As can be seen from these curves, the resonance effects are broadened as ν or ω_p is increased. Also, it can be seen that the attenuation and phase increase as ω_p increases.

V. Conclusion

From the preceding derivations it can be seen that a plasma, and in particular a plasma within a dc magnetic field, can greatly affect electromagnetic wave propagation. The existence of cutoff frequencies and stop and pass bands is of major importance when considering communication with and radar detectability of supersonic vehicles flying in or above the ionosphere. Furthermore, it is apparent that one could control the phase and/or the attenuation of a microwave signal by passing it through such a medium. This control could be accomplished by varying either the electron density or the dc magnetic field strength. The extent to which such microwave devices are of practical value is not fully known at this time.

It should be emphasized that the preceding derivations were based on a linear theory which assumed an infinite, uniform medium in the presence of a uniform dc magnetic field. If any of these conditions is relaxed, the resulting propagation phenomena may be quite different from what has been predicted in this discussion.

Acknowledgment

Portions of this work have been discussed from a different viewpoint by Dr. L. Mower in an internal report. The author wishes to thank Dr. A. J. Penico for many helpful discussions.

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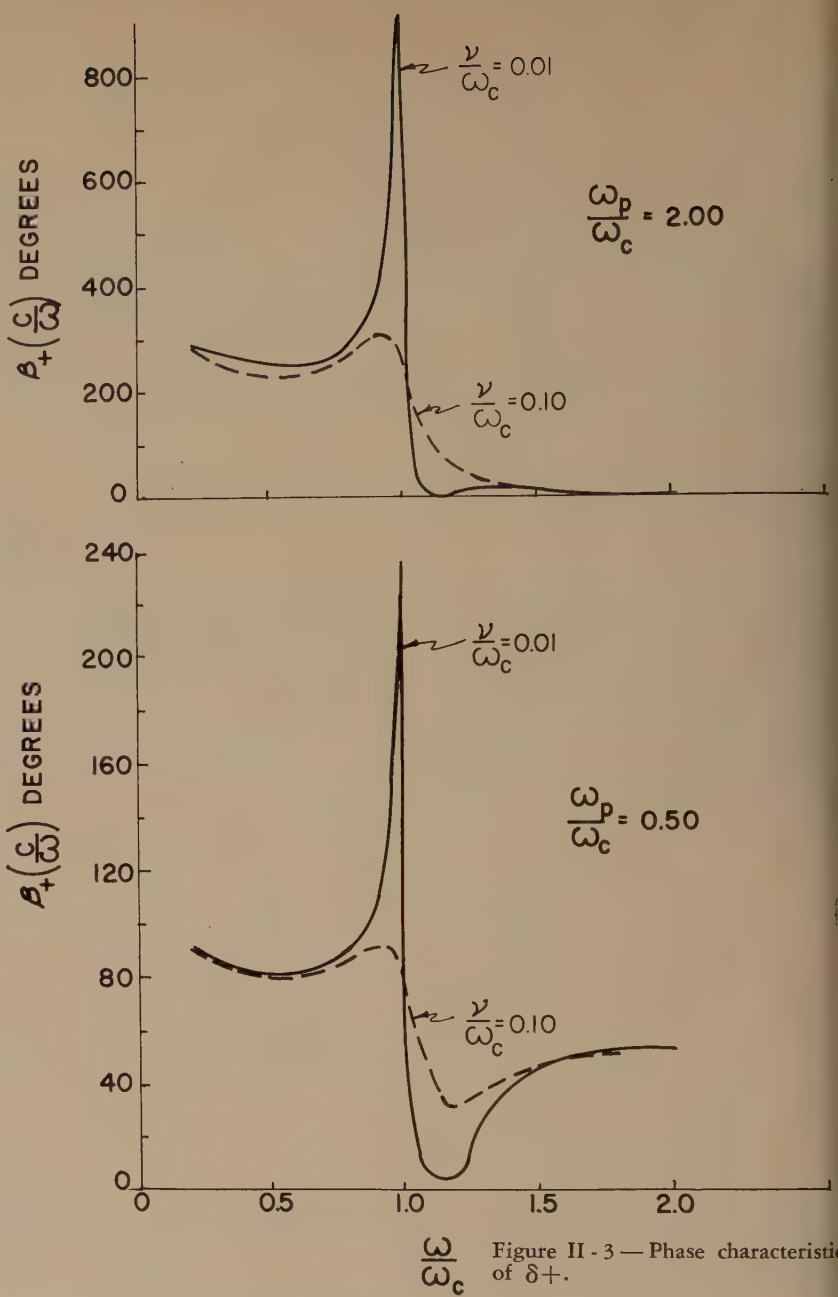

Figure II - 3 — Phase characteristic of $\delta+$.

Appendix

The elements of the matrix representing the effective dielectric tensor are

$$\epsilon_{11} = 1 - \omega_p^2 \left\{ \frac{(\omega^2 - \omega_c^2 + \nu^2) - i(\nu/\omega)(\omega^2 + \omega_c^2 + \nu^2)}{[(\omega + \omega_c)^2 + \nu^2][(\omega - \omega_c)^2 + \nu^2]} \right\} \quad \text{A-}$$

$$\epsilon_{12} = \omega_p^2 \omega_c \left\{ \frac{(1/\omega)(\omega_c^2 - \omega^2 + \nu^2) + 2i\nu}{[(\omega + \omega_c)^2 + \nu^2][(\omega - \omega_c)^2 + \nu^2]} \right\}. \quad \text{A}$$

$$\epsilon_{33} = 1 - \omega_p^2 \left\{ \frac{1 - i\nu/\omega}{\omega^2 + \nu^2} \right\}. \quad \text{A}$$

Using these matrix elements one can obtain

$$\alpha_\pm = \frac{\omega}{\sqrt{2}\,c}\left[-A_\pm + \sqrt{A_\pm^2 + B_\pm^2}\right]^{\frac{1}{2}} \quad \text{A}$$

$$\beta_\pm = \frac{\omega}{\sqrt{2}\,c}\left[A_\pm + \sqrt{A_\pm^2 + B_\pm^2}\right]^{\frac{1}{2}} \quad \text{A}$$

where

$$A_\pm = 1 - \frac{\omega_p^2}{\omega}\,\frac{\omega \mp \omega_c}{(\omega \mp \omega_c)^2 + \nu^2} \quad \text{A}$$

$$B_\pm = \frac{\omega_p^2 \nu}{\omega}\,\frac{1}{(\omega \mp \omega_c)^2 + \nu^2}. \quad \text{A}$$

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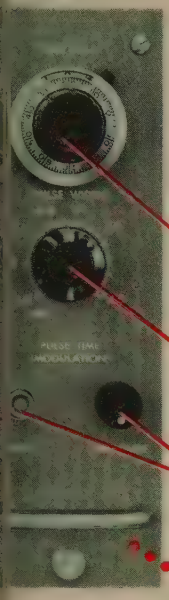

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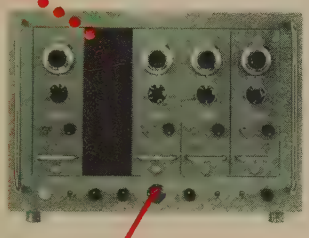

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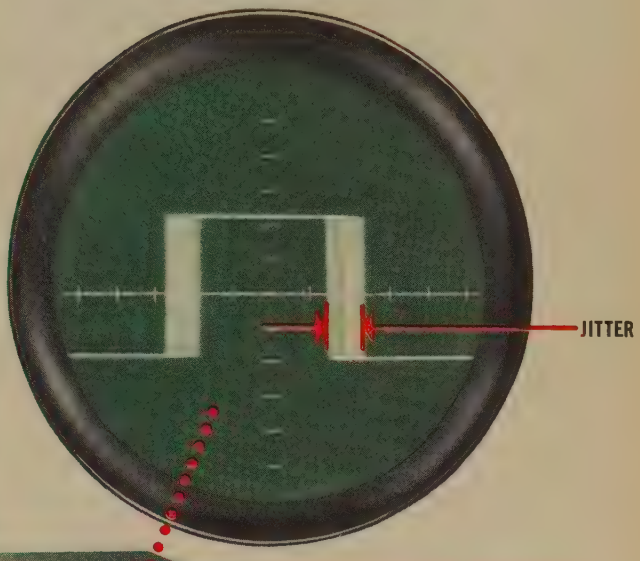

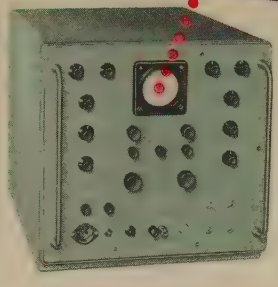

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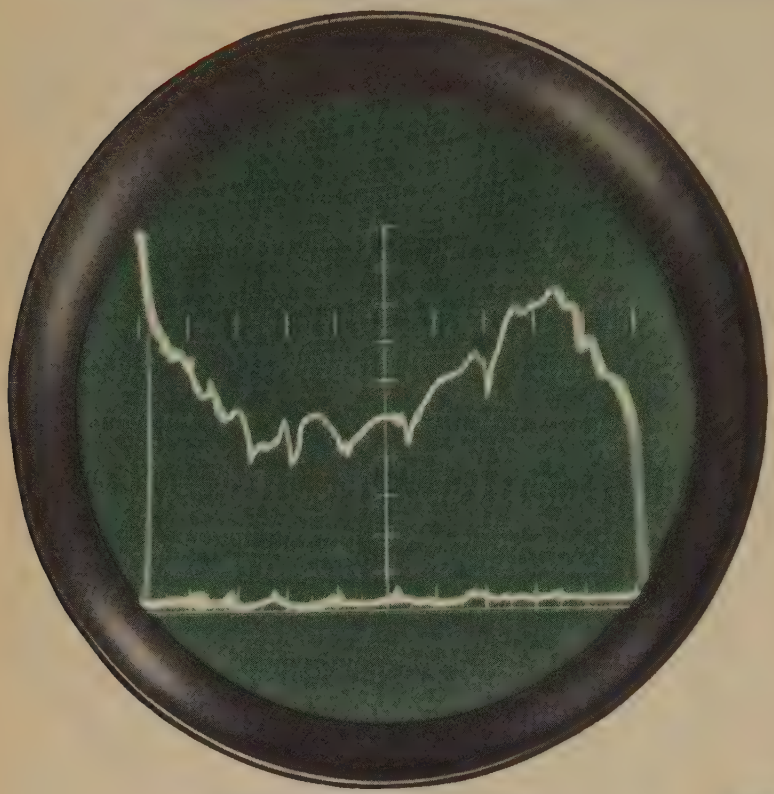

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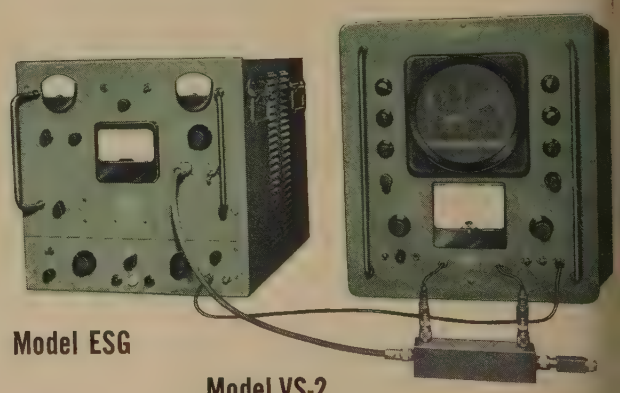

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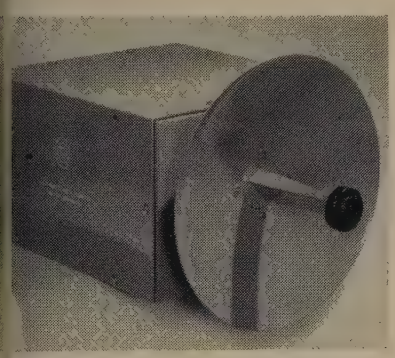

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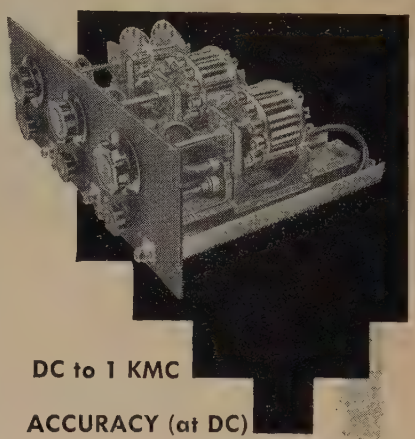

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"Ray of the Gods"

On a memorable day in 1925, Laurence K. Marshall and Charles G. Smith, co-founders of the American Appliance Company, sat down to a "brainstorming" session to devise a distinctive trade-name for their first product: a helium rectifier tube invented by Smith. In that session the name "Raytheon" was born.

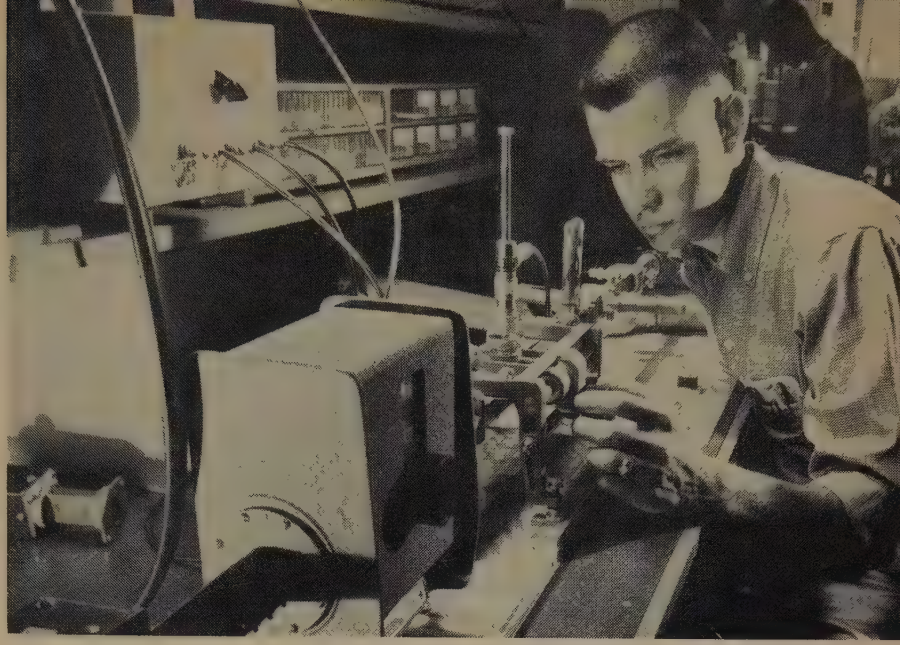
According to Marshall, "Raytheon" didn't come out of any one brain; it simply evolved. All agreed that it had exactly the right sound; and either by accident or by subconscious design, it turned out to mean "ray of the gods." This meaning, reasonably appropriate at the time, was strikingly prophetic of a company destined to become a leading pioneer in microwaves.

First Success

The Raytheon type BH rectifier tube was the sensation of the industry because it was the first to free the home radio from batteries and make it a practical plug-in household appliance. In 1926, the firm, now called Raytheon Manufacturing Company, made a profit of over $300,000 on sales of $1 million.

This success did not remain uncontested. Profits dwindled, for competition forced down the early price of $5 or $6 per tube to a figure barely above cost.

In 1929 the company moved from the original location in Cambridge, Mass. to a plant in Newton, where it weathered the depression decade by gaining and holding ten percent of the receiving tube market in the face of intense competition.



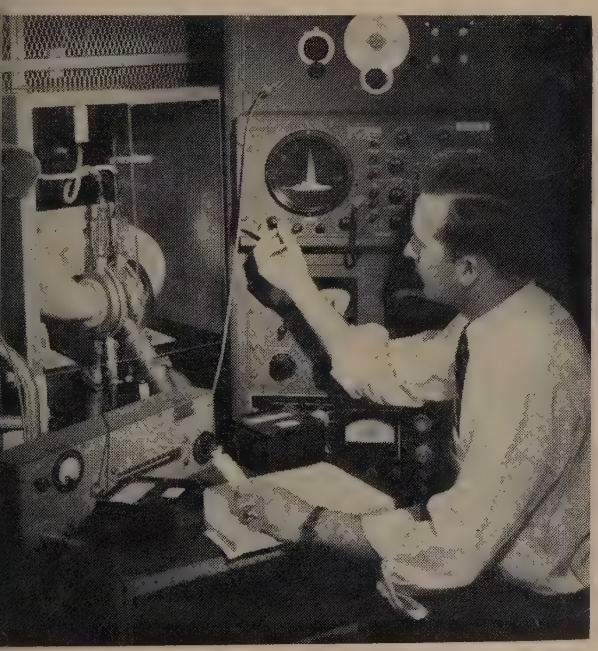
X-band and other ferrite components are electrically tested before shipment.

n 1933, Raytheon expanded its interests by acquiring
ta Manufacturing Company of Cambridge.

er Microwaves

s early as the Battle of Britain (1940-1941), a primi-
long-wave radar installation on the cliffs of Dover
playing a vital role in the defense of the British
s. British and American scientists proceeded to pool
r resources to develop improved radar sets for air,
and land and to produce them in quantity. The
ish version of the magnetron power tube had emerged
he most promising means of generating the micro-
e energy needed for sharp radar pictures. The early
gnetron, however, was a precision assembly of metal
glass which required hundreds of hours of machine
k and highly skilled labor to produce.

ate in 1940, Raytheon was awarded one of the first
gnetron development contracts and thus found itself



heon's "Amplitron," shown under test at left center, is a microwave power tube that increases energy output of rs. Added to the CAA air traffic control radars, for ex-le, this tube increases the operational range by better than 50 percent.

in the microwave field. The tricky job was entrusted to Percy L. Spencer, then head of high-frequency tube development, who had joined Marshall and Smith in 1925.

Spencer quickly converted the British prototype into a production item and commenced production, but with skilled machinists practically unobtainable, the yield was a pitiful 17 tubes a day. However, the Navy was sufficiently encouraged to build a new plant in Waltham for magnetron production. The company's executive offices were moved to this plant, thus establishing Raytheon as a Waltham institution. With improvements in design and manufacture, magnetron output reached one hundred per day by 1942.

Magnetrons by the Thousand

Meanwhile, Spencer devised a way to put the magnetron into full mass production. Instead of machining the intricate shapes from solid copper, he proposed to stamp laminations out of thin sheet stock which could be stacked and brazed to make up the required thickness. Conversion to the new process required a large outlay for dies, tools, and machines; Mr. Marshall persuaded the company to "put up $75,000 that it didn't have" for the purpose. Tube production rose to 1000 per day and eventually to 2600. Some fifty types were made. Although the lamination process was made available to other companies, 80 percent of the magnetrons received by the Navy during World War II were made by Raytheon. In the same period, reflex klystrons were produced in quantity for use as radar local oscillators.

"Eyes of the Fleet"

As early as 1941, Raytheon was awarded a contract to produce a microwave surface-search radar set for the Navy. With a design group headed by Fritz Gross (now director of engineering for Raytheon's Government Equipment Division) and including Dr. William M. Hall from the MIT faculty (who is now staff assistant to Mr. Gross), the first production equipment was completed in less than a year, and by Easter 1942 was installed on the *U.S.S. Augusta,* ready for sea-trials. This was the Model SG, the first microwave surface-search radar installed by the U.S. Navy. These sets won a reputation for ruggedness and dependability, and their material aid in the Battle of the

Roaring from its launcher, the Hawk is headed toward the skies to seek out and destroy enemy attackers. Revolutionary new radar system enables the Hawk to lock onto and destroy invading aircraft even at tree-top level, in the blind zone of conventional radar. Raytheon Manufacturing Company is prime contractor for the Hawk missile system.

Coral Sea was credited with shortening the war in the Pacific.

By 1943, Raytheon was in production on the Model SO radar, a simplified equipment packaged in several compact units for use on PT boats and LST's. A corps of several hundred field engineers was organized and factory-trained to install and maintain Raytheon radars around the globe.

Post-War Developments

Raytheon the "war baby" hit its peak in 1945, with gross sales of $173 million and 16,000 employees. After V-Day, however, sharp cutbacks were inevitable. Thanks to the Navy's continuance of development contracts, these were not disastrous, but the lack of strong commercial lines to replace Government business foreshadowed lean years ahead.

Raytheon tightened its belt. A merger with Submarine Signal Company, pioneer in underwater sound since 1901, added to radar a related field in which to serve the Navy as well as the world-famous "Fathometer" depth sounder to form the nucleus of a marine electronics line.

Well-established Raytheon commercial lines such as transformers, welding equipment, and receiving tubes were continued and expanded, but other lines such as broadcast equipment were jettisoned for lack of competitive advantage to make them pay off in the immediate post-war market. Significantly, however, the company poured money into microwave development, the field in which it was best equipped to lengthen its lead on competition. Profits on new microwave devices might be deferred, but they seemed inevitable.

Meanwhile the company went after military business on all fronts. Contracts were won from all the Services for the development of many types of radar, as well as altimeters and other related devices. There followed a gradual build-up of production contracts. Thus, even in the years before the Korean conflict, the Government continued to supply the greater part of Raytheon's business.

Commercial Radars

With the end of World War II, Raytheon turned to the development and production of radar sets for the shipping industry. By 1950, there were more Raytheon installations on commercial vessels around the globe than those of all other makes combined. This leadership has lately been contested by foreign competitors in their own territories, but Raytheon's "Mariners Pathfinder" is claimed to be the most popular radar on U.S. vessels.

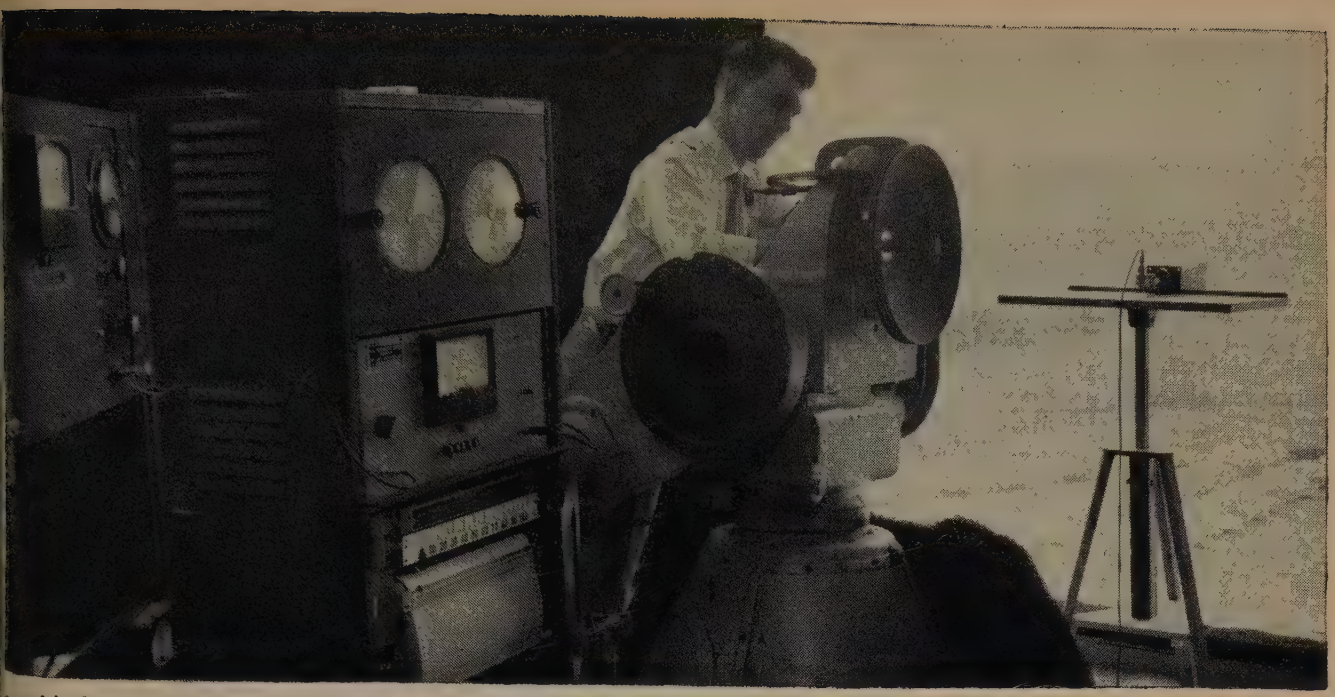
Microwave Cooking

At the close of the war, Raytheon embarked on several development programs aimed at creating useful peacetime applications for use of this microwave energy. In this way Raytheon became the pioneer in electronic cooking.

The first production model of the "Radarange" was unveiled to the public before the end of 1945 and was hailed by the press as a marvel of the new age of electronics. But further refinement was needed before the "Radarange" could live up to its press notices; consequently it was produced in very limited quantities and supplied to restaurants under leases which included free service by Raytheon engineers.

By 1950, the "Radarange" had come of age. It was as reliable as any good appliance; and with the early water-cooled magnetrons replaced by air-cooled types, installation was no longer a problem.

The new "Radarange" won quick acceptance in its intended market — the food service industry. To exploit the domestic market without entering the home appliance field, Raytheon has licensed other firms under "Radarange" patents to produce domestic models using Raytheon-built microwave generators.



In this $2,000,000 laboratory perched on a hilltop overlooking Hanscom Air Force Base, Bedford, Mass., Raytheon engineers perfect the electronic controls that send guided missiles straight to their targets.

Speed is the most dramatic feature of electronic cooking n the home. Eggs are cooked in 20 seconds, bacon in 75 seconds, a 5-lb. roast of beef in 30 minutes, and so on.

Diathermy

Concurrently with the development of the "Radarange," Raytheon investigated the application of microwaves in nedical diathermy. It was found that the ability of microwaves to develop gentle heat deep within the tissues of he body offered distinct advantages over conventional hortwave diathermy. After a period of clinical testing, the "Microtherm" microwave diathermy unit was introduced o the medical profession in the late 1940's.

Communications

The late 1940's also found Raytheon at work on the levelopment of microwave relay equipment with particular eference to commercial television, which was soon to be aunched across the nation, thus opening a huge market or network facilities. A multi-station relay link was estabished between Waltham headquarters and the company's office in New York, and developmental relay equipment was tested in successful two-way transmissions. While the original plan to provide television network service was eventually abandoned, the pioneering development work paid off in a product line of microwave relay equipment ntroduced to the communications industry in the 1950's.

Top Echelon

Raytheon's determination to build a sound peacetime ndustrial enterprise is evident in its present top management team, which represents a well-rounded combination of skills. Not only as a team but as individuals these men have won achievement in more than one professional area; hey are, in various combinations, scientists, engineers, administrators, military and financial experts, and other specialists. Some have been serving and building Raytheon or many years; others have been recruited more recently o provide needed complementary skills.

Charles F. Adams, who became president in 1948, has brought to the uncharted business of electronics a sound background of experience in investment banking and corporation finance.

Percy L. Spencer, who, during more than three decades has contributed more than any other individual to the company's success, is senior vice president.

Harold S. Geneen, formerly vice president and controller of Jones & Laughlin Steel Company, is executive vice president. An industrial organizer and trouble-shooter of wide experience, he has been instrumental in overhauling the divisional structure, improving internal controls, and strengthening functional management for greater efficiency and improved profits. Today, this structure reflects considered corporate objectives rather than the random growth of the past.

Dr. Ivan A. Getting, a scientist of international reputation, is vice president, engineering and research. His leadership has done much to attract scientists and engineers of the highest caliber to Raytheon, and to create a climate favorable to their best work.

Other members of Raytheon's top echelon, equally significant but perhaps less pertinent to this article, must be omitted for lack of space.

Raytheon Today

Raytheon is today the largest company devoted exclusively to electronics, and the largest industrial enterprise in Massachusetts. With more than 39,000 people and an annual business of about $400 million, it is still in a period of sales growth which is likely to continue in the foreseeable future.

The bulk of Raytheon's activities are centered in Eastern Massachusetts, with six engineering laboratories, six production plants, and others under construction.

There are twelve divisions, some of them cutting across state lines: Government Equipment, Missile Systems, Microwave and Power Tube, Receiving Tube, Industrial Tube, Semiconductor, Equipment and Systems, Industrial Apparatus, Distributor Products, Government Services, International, and Research.

Next month this Raytheon survey will continue with a run-down on divisions directly concerned with microwave engineering and production.

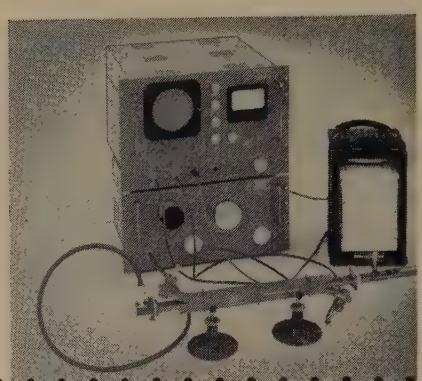
MICROWAVE INSTRUMENTS for the

- laboratory
- production line
- antenna pattern range

Direct-Reading VSWR

For instantaneous reading and recording of broadband VSWR characteristics, CTI VSWR Measuring Systems offer simplest operation and highest accuracy. Sweep-frequency systems have both meter and oscilloscope, output for recorder, and variable sweep-width.

Model 160: Sweep-frequency, 8.4 to 12.0 kmc
Model 125: Sweep-frequency, 8.5 to 9.6 kmc
Model 110: Manually tuneable, 8.5 to 9.6 kmc
Calibrated Loads: Micrometer-type, 8.5 to 12 kmc
Bi-Directional Couplers: Dual couplers as used in above systems, 16-db coupling, over 45-db directivity, 0.1-db tracking accuracy.



Magnetron R-F Supplies

Ideal as tuneable r-f sources for antenna testing ranges, the Magnetron R-F Supplies feature remote control of frequency. PRF is 1,000 pps, adjustable. Exclusive: r-f sample for amplifier AGC. Units are available for S, C, X, K_u, and K_a bands.

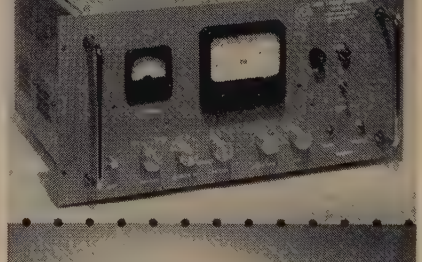
Typical specifications:
Model 154A: 8500 to 9600 mc, 35 kw nom. pk. pwr.
Model 154B: 2845 to 2905 mc, 15 kw nom. pk. pwr.

Log-Linear Amplifier

With an input accommodating bolometers or crystal detectors, the Log-Linear Amplifier provides both a logarithmic d-c output, permitting the use of conventional recorders to plot db response on a linear scale, and a linear output for precise location of antenna half-power points. Includes AGC to correct for transmitted power changes.

Variable-Polarization Antennas

Polarization of these motor-driven antennas can be remotely controlled in 45° steps. Reflector size, frequency range, power ratings, and continuously variable control can be made to your requirements.



See this equipment at the

IRE SHOW — New York City, March 23-26, Booths 1111-1112

Engineers: Career opportunities are currently available at CTI

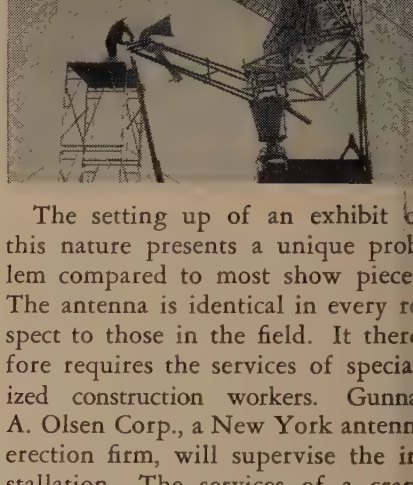
CALIFORNIA TECHNICAL INDUSTRIES
DIVISION OF TEXTRON INC.
BELMONT 3, CALIFORNIA
Foremost in Automatic Testing

D. S. KENNEDY & CO.

BOOTHS 2532 - 2637

A forty-foot search radar antenn featuring quick assembly-disassembl will be displayed by D. S. Kenned & Co. at the New York IRE Show i the Coliseum during the week c March 23rd, 1959.

This antenna is sectionalized wit no unit of the reflector weighin more than 150 pounds. It may b assembled by a trained crew in les than two hours. Rapid assembly an disassembly is achieved by means c a special Kennedy-designed fast-ac ing clamp. The antenna is intende for tactical use by the military.



The setting up of an exhibit c this nature presents a unique prob lem compared to most show piece The antenna is identical in every re spect to those in the field. It there fore requires the services of specia ized construction workers. Gunna A. Olsen Corp., a New York antenn erection firm, will supervise the in stallation. The services of a cran are required, and a considerable are is needed to assemble the sections c the antenna. For these reasons th Kennedy exhibit is first in and las out at the Show. The display of in spiring and significant electron components of this sort would b impossible without the fine cooper tion of the Show management.

Representing the company at th show will be: C. W. Creaser, Jr Kendrick H. Lippitt, Fred R. Har Jr., John Cotney and John Flynn.

• • •

F. J. STOKES CORP.

BOOTHS 4416 and 4418

Specially designed Stokes equip ment for outgassing and sealing c semi-conductor components unde vacuum will be demonstrated at th 1959 Radio Engineering Show b F. J. Stokes Corporation, Philade phia. Stokes will also exhibit i new series of small compound hig

vacuum pumps, in the 2 to 3 cfm. range, which are suitable for a number of electronic manufacturing and testing operations, such as small vacuum-metallizing units; and evacuating environmental testing chambers.

Stokes has developed a special vacuum "baking oven," which will be demonstrated at the I.R.E. Show.

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THOMPSON RAMO WOOLDRIDGE IN INITIAL I.R.E. DEBUT

Appearance of a Thompson Ramo Wooldridge booth at the 1959 I.R.E. Show and Convention marks the first composite display of products of this company's corporate family in an electronics industry show. TRW was formed in 1958 through the merger of Thompson Products, Inc., of Cleveland and The Ramo-Wooldridge Corporation of Los Angeles.

Divisions displaying the products will include the Ramo-Wooldridge division, Tapco Group, The Thompson-Ramo-Wooldridge Products Co., Dage Television, Bell Sound Systems, and Pacific Semiconductors, Inc., a subsidiary of TRW. These organizations are currently engaged in projects ranging from research and development in the fields of infrared and advanced microwave technique to stereophonic sound and closed circuit television.

Main offices of TRW are in Cleveland and Los Angeles.

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BOMAC LABORATORIES

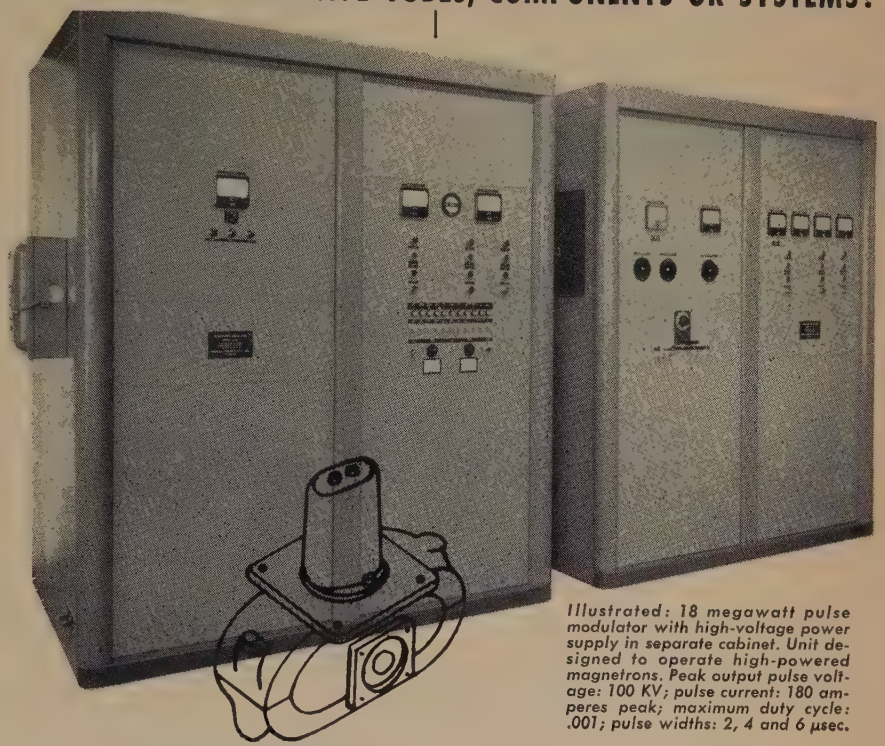
BOOTHS 2829-2831

Bomac Laboratories, Inc., Beverly, Mass., will exhibit a new line of gas switching tubes which will operate from —55 C to +125 C. These extended temperature tubes are available for all frequencies, and eliminate the need for external heating or cooling systems which results in savings of power, weight, and space. They feature excellent recovery time, and the leakage rate is safely within military specifications.

Also featured will be their complete line of microwave tubes and components including crystal protectors, magnetrons, klystrons, reference cavities, diodes pressuring windows, duplexers and surge protectors.

Testing MAGNETRONS KLYSTRONS CARCINOTRONS

● OTHER MICROWAVE TUBES, COMPONENTS OR SYSTEMS?



Illustrated: 18 megawatt pulse modulator with high-voltage power supply in separate cabinet. Unit designed to operate high-powered magnetrons. Peak output pulse voltage: 100 KV; pulse current: 180 amperes peak; maximum duty cycle: .001; pulse widths: 2, 4 and 6 μsec.

Come to Manson for the widest selection of standard *Pulse Modulators* and *High-Voltage Power Supplies* covering all useful power levels. From kilowatts to tens of megawatts, Manson has precision-engineered designs for operation and test of magnetrons, klystrons, traveling wave tubes, backward wave oscillators, lighthouse tubes, pulse transformers, waveguide components and related devices. The wide range of standard models is readily adaptable to meet individual specifications.

HIGH POWER PULSE MODULATORS:

Hard- and soft-tube types from 16 kw. to 30 megawatts peak power output, and higher. Average output powers as high as 60 kilowatts. Typical operating features include: continuously adjustable voltage control; discrete or variable pulse widths; internally- and externally-controllable repetition frequencies; auxiliary synchronized outputs; pulse-shape monitoring circuits; and interlocking and overload protection.

HIGH VOLTAGE POWER SUPPLIES:

High-voltage DC and AC types, single- or multiple-output, regulations and stabilities to 0.01%. Standard and custom designs to satisfy your specific tube testing or production problems: highly-regulated supplies uniquely suited for TWT test and operation; unregulated high-power supplies for systems testing; and complete power sources for controlling all aspects of tube production.

***Available from stock!* BASIC 1 AND 2 MEGAWATT MODULATORS**

MANSON LABORATORIES, INC.

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Booth 3225 IRE Show

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Armour Research Foundation, one of the nation's foremost independent research organizations, has appropriate positions available for experienced engineers at all levels to work on its many diversified research programs. As a member of our Electrical Engineering Research staff, you will have an opportunity to fully utilize your technical ability while enjoying excellent facilities, working conditions and stimulating staff associations.

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The Foundation is located on the campus of the Illinois Institute of Technology and encourages graduate engineering study through its education program providing tuition free graduate study, in addition to offering competitive salaries and liberal benefits including generous relocation allowance. Send complete resume to:

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G. B. Electronics Corporation

Hook Creek Boulevard

Valley Stream, L. I., New York

SAGE LABORATORIES

BOOTH 3930

Products to be featured by Sag Laboratories, Inc. at the IRE Sho will be their Slotted Line Carriag and accessories, Coaxial Rotary Join Coaxial Hybrid (Cobrid), Coaxi Pads, and numerous coaxial an waveguide crystal holders.

In attendance at the booth will b the following members of the eng neering staff: George A. Ayou John A. Camuso, Jay J. Chacran, E nest W. Lattanzi, John M. Shalhou and Robert Tenenholtz.

• • •

RAYTHEON POWER TUBE DIV

BOOTHS 2610-2614

Raytheon is featuring the recentl declassified QK634 High Pow Backward Wave Oscillator, also An plitrons, Low Power Backward Wav Oscillators, Traveling Wave Tube Magnetrons, Klystrons, and the tw new developments in Recordin Storage Tubes, the QK685 Sing Gun 1000 Line Resolution Tube an the QK703 Dual Gun Tube.

The booth numbers are 2610-261 Booth attendants will be: John De man, Frank Giacolone, John Gr ham, Maurice LaPrelle, Bob Peterso Gil Robichaud, Benno Silberma Jerry Simpson and Val Smith.

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SIERRA ELECTRONIC CORP.

BOOTHS 3031-3032

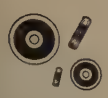
An in-circuit transistor tester an a series of monitor oscilloscopes a among the new electronic instr ments to be introduced by Sier Electronic Corporation at the 19 IRE Show in New York City, Mar 23 - 26.

Sierra, a subsidiary of Philco Co poration, designs and manufactur a broad range of electronic test i struments and systems.

metal film

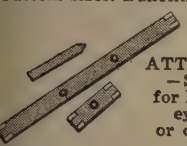
MICROWAVE RESISTORS

Highly stable—low temperature coefficient—resistance film negligibly thin even at highest microwave frequencies—tinned electrodes solder directly into RF circuit.



MICROWAVE RESISTORS—Metal film fused to PYREX base, sealed with micro-thin coating of Quartz. Tinned electrodes. Bulletin M-1

COAXIAL ATTENUATOR ELEMENTS for ⅜ inch to largest line size. Solder or pressure mount. Standard and Custom sizes. Bulletin L-1



METALLIZED GLASS RECTANGULAR ATTENUATOR ELEMENTS—Standard plates available for L thru K band. Metallized eyelet for solder mounting, or drilled holes. Bulletin A-1

FILMOHM RESISTANCE CARD—Micro-thin metal resistance film deposited on high temperature fibre glass plastic sheet. Electrically uniform film, dimensionally stable, simple to fabricate. Available from 25 to 750 ohms per square, and .025, .032, or .062 thick. Bulletin P-2

FILMOHM METALLIZED MICA—Micro-thin metal resistance film deposited specially surfaced natural mica. Use as rotary and guillotine attenuator elements and loads. Ideal for mm frequencies and in stripline. Available in large uncut sheets or fabricated parts, .001 to .005 thick, 25 to 400 ohms per square. Bulletin C-1

STRIP LINE RESISTORS—Thin mica base metal film resistor as thick as the copper strip line, cement directly on the plastic base into strip line circuit. Used as pads, attenuators, and loads. Width, length, and thickness as required. Bulletin SL-1

HIGH POWER COAXIAL LOAD RESISTORS—Metal film tubular glass resistors suitable for air, oil, or water cooling. Used as dummy loads, damping, and terminations. Non-inductive, films are not spiraled or striped. Standard and custom sizes up to 4 feet long. Bulletin HP-1

CERAMIC FILM RESISTORS—Metal Resistance Film on Ceramic Base. Highly stable disc resistor, mechanically strong, LOW COST. Tinned or silver electrodes for pressure mounting. Bulletin CD-1

FILMOHM CORPORATION

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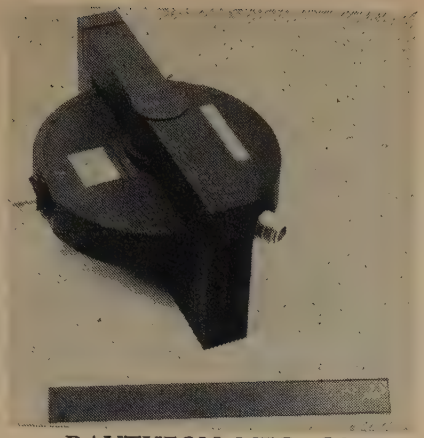
New York 10, N. Y.
WAtkins 4-3244

CIRCLE READER SERVICE CARD 25



RAYTHEON MFG. CO.

BOOTHS 2610-2614

The Special Microwave Device Group will feature several devices of which the most significant will be the maser circulator for L-band.

This three-port device has Type N coaxial connections and is designed for use with masers and parametric amplifiers at L-band. The unit, designated CLL1, combines extremely low insertion loss with small size and weight. Typical performance is 0.3 db insertion loss, 25 db isolation with VSWR less than 1.1 centered at any frequency from 1000 mc/s to 1600 mc/s. With a permanent magnet, performance is 0.4 db to 20 db with VSWR 1.2 over any 50 mc/s band.

Also to be shown will be a UHF isolator covering the frequency band 500-700 mc/s as well as a miniature mock-up of the recently developed 350-400 mc/s isolator.

A new high power S-band circulator will also be shown along with many of the standard devices ranging from UHF through K-band. Booth personnel will be Dr. Howard Scharfman, Group Manager; Dr. Colin Bowness, Technical Director; Mr. Ralph M. Moschella, Sales Manager.

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SCIENTIFIC ATLANTA

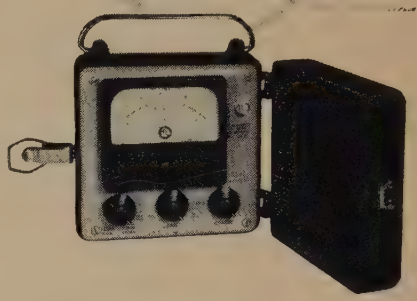
BOOTH 1226

Scientific-Atlanta, Inc., Georgia, announces that their Model 301 Remote Tuned Signal Source will be shown for the first time at the New York IRE Show.

The remote tuning feature of the Model 301 makes the signal source especially suited for antenna test applications where the source must be located at great distances from the receiving site. The weatherproof Carcinotron RF Heads cover the frequency range from 100 to 16,000 mcs. The power output varies from 500 mw to 5 mw over this frequency range.

TEST INSTRUMENTS for *LABORATORY/PRODUCTION FIELD TESTING*

measure microwave power directly, quickly, accurately



TRANSISTORIZED POWER BRIDGE

The AIL Type 50 R-F Power Bridge applies the most advanced transistor circuitry techniques to power measurements in the 10-40,000 MC range. Full scale ranges of 1.0 and 10 milliwatts and plus and minus 10dbm are provided. Accuracy within 0.5 db.

Compact—battery operated—weighs less than 4 pounds—hand held—ideal for field applications.

Each Type 50 is carefully checked and tested under the rigid AIL quality control system assuring highest reliability for a variety of applications in:

Radar • Communications
Navigation • Telemetering
Television • Transmission lines
Microwave links • R-F leakage

Price *$199*

Airborne Instruments Laboratory

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A Division of Cutler-Hammer, Inc.

CIRCLE READER SERVICE CARD 26

DIELECTRIC PRODUCTS

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AMPHENOL ELECTRONICS

BOOTHS 2317-19-21-23-25-27

Series MM — a complete line of crimp-type microminiature RF connectors — has been announced by IPC Division of Amphenol-Borg Electronics Corp. Initial release is comprised of plugs, jacks, bulkhead jacks, right angle plugs, hermetically sealed receptacles, bulkhead adapters, bulkhead receptacles, printed circuit receptacles and caps in screw-on and slide-on coupling. Three impedances — 50, 70 and 93 ohms — match standard subminiature RG-/U coaxial cables.

The IPC division will feature: Series MM microminiature RF connectors, Triaxial Connectors, Printed Circuit Coaxial Connectors, UG-/U Connectors, Radiation-Resistant Connectors.

The Danbury-Knudsen division will feature: Coaxial Relays and Switches, including hermetically-sealed types; Coaxial Attenuators, Rack & Panel Connectors, Microwave Components.

The Amphenol Connector division will feature: Connectors for Aircraft, Missiles, Communications, Computers and other electromechanical applications. Specialty developments for electronics. RF Coaxial Cables, Wire and Cable Products.

• • •

GENERAL RADIO

BOOTHS 3302-3312

A group of outstanding new instruments for the electronics laboratory will be displayed by the General Radio Company of West Concord, Massachusetts, at the 1959 Radio Engineering Show. This exhibit, is the largest and most comprehensive in the Company's history. Over 100 products will be exhibited including the following brand new items:

Universal Impedance Bridge, Precision Inductance Bridge, Graphic Level Recorder, Time-Delay Generator, Vacuum-Tube Bridge, Low-Frequency Three-Phase Oscillator, Pulse, Sweep and Time-Delay Generator, Standard Frequency Multipliers, and Sound-Level Meter.

• • •

LAVOIE LABORATORIES

BOOTHS 3502-3504

A new version of Model LA-70 VHF Frequency Meter will be introduced by Lavoie Laboratories, Inc., at the IRE Show. Frequency

See us at BOOTH 1107 IRE SHOW

new from Cascade...

BROADBAND FERRITE LOAD ISOLATORS

designed for test equipment applications

SIX MODELS

kmc	isolation db	Model	Price
8.2—12.4	30	X—12•29	$220
8.2—12.4	40	X—12•25	270
7.0—10.0	30	XL—12•10	245
7.0—10.0	40	XL—12•7	295
5.85—8.2	30	J—12•70	220
5.85—8.2	40	J—12•65	270

GENERAL SPECIFICATIONS

Power capability, watts, forward . . 10
Power capability, watts, absorbed . . 2
Insertion loss, db max 1.0
Input vswr into flat load, max . . . 1.1

Send now for additional detail on these Uniline Isolators, or get in touch with us on any problem you have concerning microwave ferrite devices.

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AN/APS-10 3CM. RADAR

3cm. PPI 10kw output, hydrogen thyratron mod. .8 microsec. rcvr 30 mc IF 5.5 mc bandwidth. Uses 30 tubes 3xtals plus 2J42 magnetron, $750 ea. Full desc. MIT. Rad. Lab. series Vol. I pp 616-625. RF head alone $375.

AN/APS-31A RF HEAD

4J52 Magnetron, 100kw x band — complete RF Plumbing, beacon reference cavity 6AK5 IF Strip, receiver. New with all tubes. $385

RT39/APG-5 10CM RADAR

500 watts. Complete S band RF package. Lighthouse 2C40 xmtr, 2C43 rcvr, TR, 829B pulser, miniature 6AK5 IF strip. Press. 12" dia., 24" lg. All brand new tubes $275

X BAND KLYSTRON MOUNT

PRD type for 2K25 with variable attenuator. Completely Shielded. 1" x ½" output. Brand new $45.00 Special price.

SCR 584 — SKYSWEEP ANTENNA PEDESTAL MP-61B

Full azimuth and elevation sweeps, 360 degree azimuth, 205 degree elevation. Accuracy + one mill or better in angle, 6 ft. dish, fully desc MIT, Radiation Lab. series Vol. I pp 284 and 209, Vol. 26, pg 233. For full tracking response. Includes pedestal drives selsyns, etc. Excellent used condition. First time these pedestals have been available for purchase.

F-28/APN-19 FILTER CAVITY

Jan. spec: Tuneable 2700-2900mc. 1.5db max. loss at ctr. freq. over band. New, $37.50 each.

SPERRY POWER KLYSTRONS

SMX-32 Amplifier - Multiplier 9.0 - 10.5 KMC. Amp. freq. multiplier; output power 1.5 to 2 watts at 9000 to 10,500 mc; drive freq. 4500 to 5250 mc. New in original sealed cartons. Guaranteed. Regular price $925 ea. Our price $425 ea.

SMC-11A Frequency multiplier. Output range 4640-4670 mc. ½ to 1 watt on 6th harmonic. Input range 773-778 mc. For direct crystal control of microwave frequencies. New in original sealed cartons. Guaranteed. Regular price $1500 ea. Our price $495 ea.

2 MEGAWATT PULSER

Supplies 2 megawatts to magnetron at pulse duration of 2 microseconds. 4C35 Hydrogen Thyrotrons. Brand new complete. General Electric $1150.

FOR SALE: IN STOCK — COMPLETE RADAR SYSTEMS

SCR 584 30 ft. trailer Skysweep antenna system. PPI indicator + RHI 10 cm. High power for airway control missile-satellite tracking, radio astronomy R & D. As new Complete. 5 sets now available at new special price.

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AN/APS-10 Complete airborne Radar Mfg. by G.E. 3cm. using 2J42 Magnetron for Navigation, Mapping, Weather, Collision Avoidance $750

AN/MPN-1A (GCA) Ground Control Approach Radar, 30 ft trailer with 3cm precision and 10cm Search Radars as used by CAA. Full desc. Vol. 11 MIT Rad. Lab. Series Sec. 8.13.

WEATHER RADAR 275 kw. 10 cm. Compact wt. 488 lbs. rotating yoke PPI 4, 20, 80 mile ranges, ideal for weather forecasting. Lab. Brand new. FCC approved $950.

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range of the unit is 10 kc to 3,000 mc. The unit is accurate to 1 part per million over a range of 20 mc to 3,000 mc, and reaches full measuring accuracy with only a 20-minute warm up.

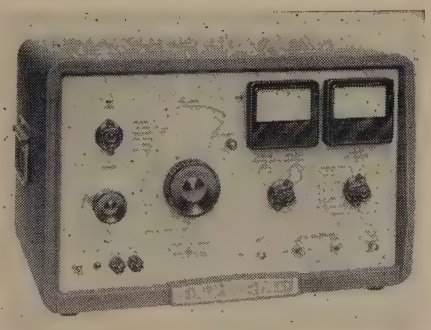
NEW PRODUCTS

NEW MODEL 606A SIGNAL GENERATOR

A new signal generator covering the broad frequency range from 50 KC to 65 MC is now available from the Hewlett-Packard Company.

The instrument, Model 606A, is particularly useful in driving bridges, antennas and filters, and for measuring gain, selectivity and image rejection of receivers and IF circuits. Output is constant within ±1 db over the full frequency range, and is adjustable from +20 dbm (3 volts rms) to —110 dbm (0.1 microvolt rms).

The constant output impedance of Model 606A assures high measurement accuracy. A 10:1 voltage divider and dummy antenna, lowering minimum output to 0.01 microvolt (from 5 ohms) or simulating the IRE standard dummy antenna, is available for precision receiver measurements.

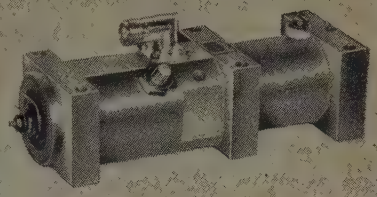


The new generator may be modulated by sine waves and complex waveforms from dc to 20 KC. A meter indicates percent modulation. Output distortion is extremely low due to the use of a feedback circuit.

To insure maximum accuracy of frequency setting, Model 606A includes an internal crystal calibrator providing check points at 100 KC and 1 MC intervals with an error of less than 0.01%.

CIRCLE READER SERVICE CARD 102

NEW



AVION

"S" - BAND

pulse oscillator

model no. 306

- *offering superior stability for both vibration and temperature under extreme environmental conditions . . .*
- *small-size and light-weight*

TUNING RANGE 300 MC (Nominal)

POWER OUTPUT 1.5 KW peak minimum at .001 duty cycle, 1 μsec pulsewidth, 1000 pps

TUBE GE 6442 triode

OPERATING CONDITIONS 3000 V at 2.5 amp peak (Nominal) Heater 6.3 V ac or dc (5%)

VIBRATION 20 g . . . 20-2000 cps (FM 2 MC max.)

SHOCK 70 g while operating (frequency shift 1 MC max.)

Temperature —50 C to 100 C (4 MC max.)

FIXED CATHODE Plate tuned (only tuning adjustment)

TUNING LOCKING DEVICE Output connector (type N, TNC, or BNC, nominally 50 ohms)

OVERALL DIMENSIONS Length 6-1/4"; Width 2"; Height 1-7/8" excluding connector

WEIGHT 20 oz.

MOUNTINGS Integral parts of the oscillator — included in the dimensions and weight, above

OTHER MICROWAVE COMPONENTS S, C, and X — bands available.

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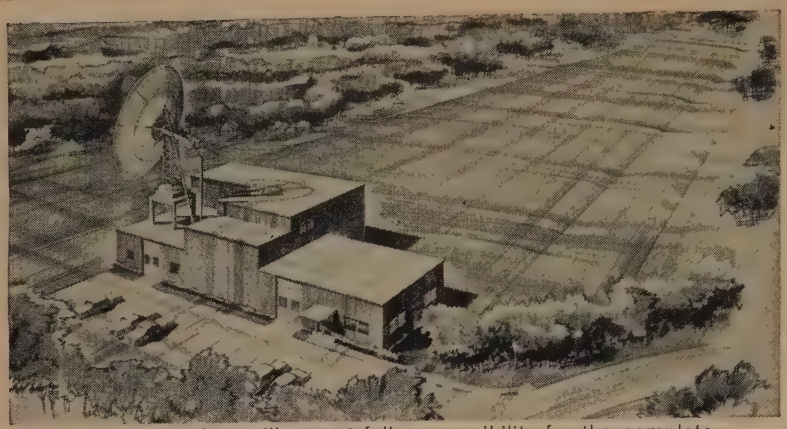
Antenna Test Facility



Scientific-Atlanta, Inc. will accept full responsibility for the complete design, construction and instrumentation for any antenna test facility to meet your requirements.

Instrumentation includes

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★ ANTENNA POSITIONERS ★ TRANSMITTING ANTENNAS
★ WIDE RANGE RECEIVERS ★ MODEL RANGE TOWERS

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Write for our Handbook on Antenna Measurements or pick one up at our booth at the IRE Show.

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MICROWAVE ASSOCIATES

BOOTHS 2301-2303

Among new items featured in Mi crowave Associates' new booth at th IRE Show will be their Varactor Di odes and the Harris Negative-Resis tance Parametric Amplifier. Also i the semiconductor line will be micro wave diodes for mixer and video de tector applications with particula emphasis on the broader line of co axial and tri-polar units designed b Microwave Associates.

Also new will be a comprehensiv line of Ferrite Isolators, Circulators and Duplexers. Gas Discharge Du plexers will include many TR, PRE TR, ATR, and Crystal Protecto Tubes recently developed by Micro wave Associates.

Microwave Magnetrons will b generally the ruggedized, small tub types designed to meet specialize requirements of missile, airborn and portable applications. Include are some of the latest tunable an fixed-tuned designs in the X and K Bands.

President Dana W. Atchley, Jr Vice President and Sales Manage George S. Kariotis, and Sales Eng neers Erik Stromsted and Richar Dibona will represent the firm IRE.

• ● •

HEWLETT-PACKARD

BOOTHS 2509-2515

Latest techniques and instrumentt tion for making basic electronic mea urements will be demonstrated H Hewlett-Packard Company at th 1959 IRE Show in New York Cit March 23 - 26.

The company, world's largest ma ufacturer of electronic measurin equipment, will introduce 12 maj new instruments at the show. The and other Hewlett-Packard instr ments will be arranged in actual te setups to demonstrate the speed, co venience and accuracy provided modern instrumentation.

The Hewlett-Packard booth w feature all major areas of electron measurement, including voltage, f quency, current, waveform, time a microwave. Visitors to the boo will be invited to make their ow measurements of specific phenomen

A dozen new instruments will shown for the first time by Hewle Packard at the IRE Show.

SYMPOSIUM ON MILLIMETER WAVES

The ninth international symposium organized by the Polytechnic Institute of Brooklyn's Microwave Research Institute will be held on March 31, April 1 and 2, 1959 in the Auditorium of the Engineering Societies Building (33 W. 39 Street in New York City).

The Symposium on Millimeter Waves has been organized into six sessions:

The introductory session (on Tuesday Morning, 31 March 1959) includes a "Survey of Millimeter Waves in Communications" by S. E. Miller of the Bell Telephone Laboratories, a "Survey of Millimeter Waves in Physics" by W. Gordy of Duke University, and a survey of Millimeter Wave Work in Russia by a representative of the U.S.S.R. Academy of Sciences. A paper by W. Low of The Hebrew University of Israel on "Paramagnetic Substances Suitable for Maser Operation in the Millimeter Range" will conclude this session.

The afternoon session on Tuesday, 31 March 1959 will include six papers on Solid State Active Millimeter Wave Circuits and Measurement Techniques, namely:

Highly Anisotropic Magnetic Materials for Millimeter Wave Applications — D. J. De Bitetto, F. K. du Pré and F. G. Brockman — Philips Laboratories, N.Y.

Microwave Hall Effect in Germanium and Silicon at 70 KMC — G. E. Hambleton and W. W. Gärtner — U.S. Army Signal Research and Development Laboratory

Millimeter Wave Program at Lincoln Laboratory — G. S. Heller — Massachusetts Institute of Technology

Use of Multiple Polarizations for Electron Density Profile Measurements in High-Temperature Plasmas — R. Motley and M. A. Heald — Princeton University

Pendulum Method for Power Measurement in Millimeter-Wave Region — H. Yamamoto — Chiba University, Japan

A New Method for Dielectric Measurement at Millimeter Wavelengths — A. L. Cullen — Sheffield University, England

The sessions on Wednesday, 1 April 1959 are devoted to Millimeter Wave Generation including a number of outstanding new ideas and developments:

The Generation of Sub-Millimeter Waves and Fast Wave Amplification — H. Motz and M. Nakamura—Oxford University, England

Experimental Study of Undulator Radiation — D. Walsh — Oxford University, England

High Power Gas Discharge Frequency Multiplier — J. R. Baird and P. D. Coleman — University of Illinois

The Dielectric Tube Resonator — A Device for the Generation and Measurement of Millimeter and Submillimeter Waves — R. C. Becker and P. D. Coleman — University of Illinois

A Millimeter Wave Multiplier Using the Purcell Radiator — J. Bradshaw — General Electric Company, Schenectady, N.Y.

Cyclotron Resonance and Generation of Millimeter Waves — A. Reddish — General Electric Company, England

A Proposed Millimeter Wave Generator — G. Kino — Stanford University

Generation of Microwaves by Cerenkov Radiation — H. Lashinsky — Columbia University

Electron Beam Interaction with Fast Waves — R. H. Pantell — Stanford University

Reflex Klystrons for Millimeter Waves — B. B. van Iperen — Philips Research Laboratories, Netherlands

O' Carcinotrons for the MM Range — G. Convert — C. S. F., France

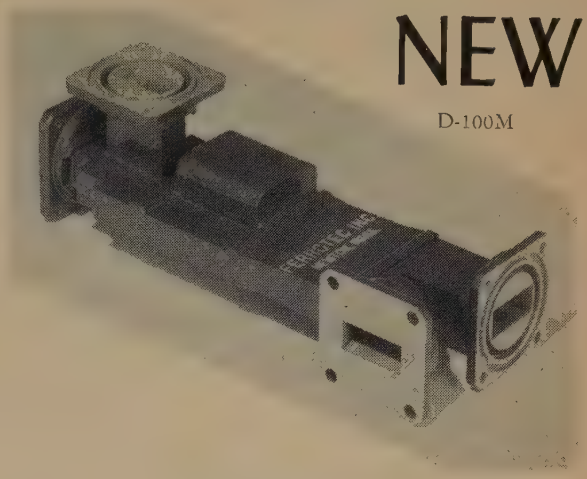
Traveling-Wave Tubes Using Multiple Lattice Structures and Paralleled Electron Streams — C. K. Birdsall, R. W. Grow and R. M. White — General Electric Company, California

The Thursday Morning session on 2 April 1959 will study the special transmission problems that arise at millimeter wavelengths and recent advances in millimeter wave components.

(*Continued on page 64*)

FERRITE CIRCULATOR NEW

D-100M



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TEMP. RANGE —50°C to 150°C	WAVEGUIDE - RG 67/U

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WEIGHT 12 oz. PART NO. D-100M

POWER RATING 250 kw Peak — 300 watts Av.
WEIGHT 16 oz. PART NO. D-200H

Ferrotec Inc. produces all types of microwave ferrite components. Call the sales representative in your area:

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Engineers

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and **ANTENNA SECTION**

The Microwave and Antenna Section operates in the areas of microwave component and microwave system development, microwave instrumentation, standardization, antenna development and bid and proposal preparation as related to systems.

The group will undertake problems in typical applications such as radar, communication, beacon, electronic countermeasure, navigation sets, transmission systems, instrumentation techniques and gain calibration. Development will be effected on such items as horns, reflectors, antenna assemblies, arrays, linear and circularly polarized antennas, and radomes.

Qualified engineers with a BS in EE or Physics (advanced degree very desirable) and a minimum of 5 years experience are urged to inquire about the openings immediately available.

MICROWAVE COMPONENTS: *There is a need for development and design engineers with experience in the areas of: directional couplers, mixers, equalizers, filters, power dividers, rotary joints, special instrumentation devices.*

ANTENNAS: *Engineers with experience in broadband microwave antennas are needed. The group will be responsible for all phases of antenna development and design, from initial conception through prototype.*

Please write to Norman C. Gibbs

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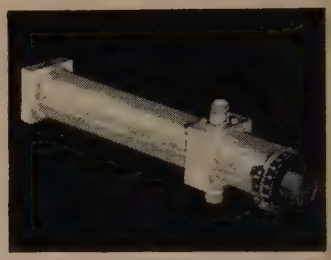

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CIRCLE READER SERVICE CARD 34

Symposium on Millimeter Waves

(*Continued from page 63*)

Papers by J. W. E. Griemsmann, L. B. Felsen, W. Kahn, and H. Kurss of the Microwave Research Institute will cover Millimeter Lines and Components and Multiport Network Characteristics which are of special importance to millimeter waveguide and oversize waveguide systems.

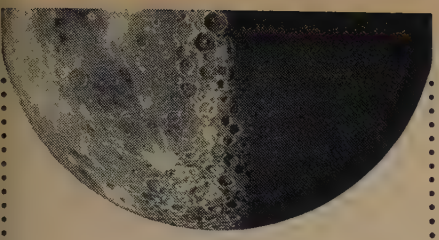
The extensive contributions of D. Marcuse, E. A. Marcatili, H. E. Rowe, H-G. Unger, W. D. Warter, J. A. Young and others at the Bell Telephone Laboratories will be presented in two papers covering phenomena and measurements in multimode waveguide and cavities.

R. C. Honey will describe work at the Stanford Research Institute on "Line-Source Arrays for Millimeter Wavelengths."

The session will conclude with a paper by L. Lewin of the Standard Telecommunication Laboratories, Ltd in England on "Quasi-Optical Methods at Millimeter Wavelengths."

Dr. John R. Pierce of the Bell Telephone Laboratories will act as Chairman at a Round Table Discussion of Future Trends and Applications of Millimeter Wave Research which is scheduled as the closing session on Thursday Afternoon, 2 April 1959.

Abstracts of all papers, a detailed program and registration forms are available from:
The Microwave Research Institute, Polytechnic Institute of Brooklyn, 55 Johnson Street, Brooklyn 1, N.Y.



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Experienced in the field of particle physics, magneto-hydrodynamics and plasma physics, comparative performance of electrical propulsion systems, new methods of developing thrust from electrical propulsion systems, and direct conversion processes.

Chemical Physicists

To make studies on propellants for ion propulsion. Experienced in electronics, atomic physics, and physical chemistry.

Physicists

Primary activities will be in the field of ion sources and high vacuum techniques. Experienced in particle accelerators, ion sources, and electronics.

Electrical Engineer

Analysis of electrical power generators, preliminary stages designs of permanent magnet, AC induction and electrostatic generators.

Please write. Mr. M. C. Jamieson, Engineering Personnel Dept., 6633 Canoga Avenue, Canoga Park, Calif.

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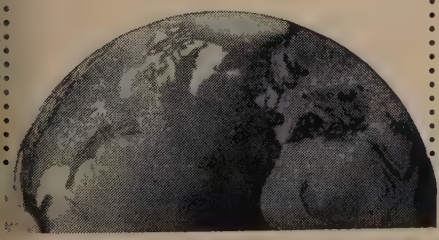
FIRST WITH POWER FOR OUTER SPACE



NEW AIRTRON PLANT IN FULL OPERATION

Mr. David Ingalls, President of Airtron, Inc., a division of Litton Industries has announced that the expanded facilities recently acquired in Morris Plains, New Jersey have been placed into full operation.

The new 100,000 sq. ft. building is the home of the company's Microwave Electronics, Guideline, and Cambridge Ferrite Divisions.

Airtron's additional manufacturing facilities in Linden, New Jersey, and in Los Angeles, California, will be retained for other phases of the company's operations.

• ● •

ETHEL PALIOCA SELLING FOR PREMIER INSTRUMENT CORP.

Ethel Palioca will carry on as Sales Representative in the New England area for Premier Instrument Corp., Port Chester, N.Y., in place of her husband, Wayne Palioca, who was recently killed in an auto accident. Wayne will be missed by his many friends in the industry.

His widow is making a very brave effort and all at Premier are rooting for her. They feel certain that all Wayne's friends will feel likewise.

At Premier this is a first, as she will be the first of her sex to represent the company.

• ● •

MID-AMERICA ELECTRONICS CONFERENCE

The eleventh annual Mid-America Electronics Conference (MAECON-1959) will be held this year in the spacious Kansas City Municipal Auditorium and Hotel Muehlebach on November 3, 4, and 5.

Technical papers are wanted on Engineering Management, Engineering Education, Astronautics, Electro-Magnetics, Nucleonics, Airborne Electronics, Medical Electronics, and other Electronic subjects. Abstracts of approximately 100 words should be sent not later than July 1 to: Dr. Sheldon L. Levy, Midwest Research Institute, 425 Volker Boulevard, Kansas City 10, Missouri, or Dr. Charles Halijak, Kansas State College, Manhattan, Kansas.

Inquiries concerning exhibition booth space should be sent to: Mr. John V. Parks, Exhibits Chairman, Bendix Aviation Corporation, P.O. Box 1159, Kansas City 41, Missouri.

• ● •

ENGINEERS AND PHYSICISTS R & D ON NEW MICROWAVE DEVICES

Microwave Associates, Inc. invites qualified engineers and physicists to discuss an unusual opportunity to perform R & D work on new microwave devices utilizing ionized media, ferrites and semiconductors. A broad background can be achieved in the interaction of electromagnetic energy with non-linear lossy dielectrics. Here is an opportunity to grasp the advantages of each medium, combine their properties, and develop new devices.

Excellent high power and low power facilities are available for complete study and test of these devices over a wide frequency spectrum — 400 to 70,000 MC.

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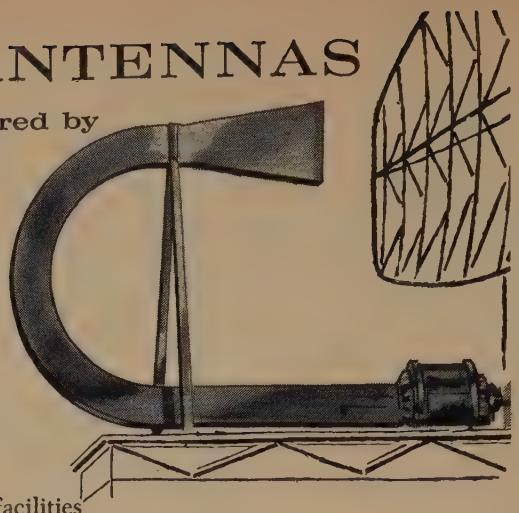

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- cavity type tuners • slip ring assemblies
- fabricated and precision cast wave guides
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TARGET GENERATOR BY REMANCO, INC.

The MTG 100X is an X-band microwave radar test set capable of providing a delayed target to a pulse radar at its microwave frequency. The target pulse is locked to the radar frequency by means of an AFC loop.

The incorporation of a klystron with linear reflector tracking permits frequency tuning to be achieved by a single dial. A potentiometer geared to the tuning shaft causes the klystron to automatically track the mechanical tuning. Power output is adjustable from —10 to —80 dbm.

CIRCLE READER SERVICE CARD 110

• ● •

HIGH POWER LIGHTWEIGHT FERRITE CIRCULATOR

An improved Ferrite Circulator has been developed by Ferrotec Inc., Newton, Mass. Specifically designed for those applications where weight and size are at a premium, this is a high performance component with 25 db isolation; and 0.5 db insertion loss. Measurements under peak power at a temperature of —55°C show no deterioration of performance. Two models are available in the 8700 to 9600 Mc/s frequency range.

The 150 kw rated unit weighs 12 ounces. The 250 kw rated unit weighs 16 ounces.

The waveguide is RG 67/U and VSWR 1:15 max.

CIRCLE READER SERVICE CARD 111

• ● •

HIGH POWER COAXIAL TERMINATIONS BY RADAR DESIGN CORP.

RDL-30N is a member of a line of high power coaxial terminations released by RDC to cover the range DC-10KMC. RDL-30N is rated at 200 watts without forced cooling. VSWR is below 1.2 to 4 KMC.

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Notes of the Industry

ENGINEERING INCENTIVE

PAUL H. ODESSEY
POLARAD ELECTRONICS CORPORATION

Paul H. Odessey was born on September 4, 1912 in Brooklyn, New York. He received his primary and secondary school education in the public schools of New York City. Upon graduation from Brooklyn Evening High School in 1931, he matriculated for a course in Electrical Engineering at Brooklyn Polytechnic Institute. He received the degree of Bachelor of Electrical Engineering, cum laude, in 1935. He was elected a member of Tau Beta Pi and Eta Kappa Nu.

Following graduation, he accepted the Electrical Engineering Fellowship at Brooklyn Polytechnic Institute whcih enabled him to study for a higher degree and to pursue graduate research.

In 1937 he joined the engineering staff of Heyer Products, Belleville, New Jersey, as a development engineer. In 1939, he received a position with the C. J. Taglabue Company as a senior development engineer in the instrument and control division under Dr. C. O. Fairchild, former Bureau of Standards authority. In 1942, he accepted the position of senior engineer with the Raytheon Manufacturing Company, Waltham, Massachusetts, and remained here throughout the war until just after V.E. Day in 1945. In 1945 he resigned from Raytheon to join in a partnership with D. L. Jaffe to found Polarad Electronics Company, which became Polarad Electronics Corporation in 1949. By 1955, the company (now located in Long Island City) under guidance by the founders, had achieved professional recognition in the field and had expanded to a plant capacity of over 600 employees occupying 150,000 square feet.

Mr. Odessey's present position is Executive Vice President and Chief Engineer of Polarad Electronics Corporation.

ONE OF THE major problems facing management today is how to maintain an efficient and effective engineering organization. The measure of achievement, while not always clearly defined, is related to the profitable operation of such an organization. Research and engineering work have always been considered marginal where profit is concerned and something to be amortized over a long period to recover costs.

One of the established approaches to make engineering operations more efficient has been along organizational lines; that is, to divide responsibility and to channel effort through various departments, groups and individuals. Through the organizational set-up substantial progress has been made but there still remains the intangible element that goes into all research and engineering work. Scientific accomplishment depends a great deal upon the creative ability and personality of the individual, as well as many other interdependent factors. These problems have made research and engineering work risky and uncertain. As a consequence, most research and development work supported by the Government or industry is on a "cost plus" basis. While this practice eliminates the business risk of research and development work it does not establish a competitive atmosphere towards accomplishment. Expressing this realistically, it is performing a difficult technical task on the "best efforts" basis without financial risk; indeed, there may be no relationship between money spent and accomplishment. The penalty in overrunning cost is a lower rate of profit, but hardly ever a loss. This does not mean that the system of cost plus fixed fee is without merit. Many projects are so large in scope and contain so many intangibles that this type of work could not be under-

taken by a commercial organization without some safeguards.

It seems that although we must have this approach to unusual research and development programs, a substantial increase in efficiency would be obtained if the needs of the engineer were better understood. The engineer or research worker has from time to time outlined conditions, apart from salary, that he believed important to his personal well-being. Some of these are:

1. A creative atmosphere.
2. The opportunity of doing challenging work.
3. A reasonable sense of security.
4. Recognition of work well done.
5. Pleasant surroundings.
6. Good cultural environment.
7. Responsive management.

In addition, there are the usual fringe benefits, including health insurance, retirement, holidays, sick leave, profit sharing and stock options. Some or all of these benefits are applied uniformly within a given organization with perhaps some special consideration to key employees. Apart from promotions or special assignments, there are seldom individual awards made for work on a particular project. This is due mainly to the size of the project and the difficulty of singling out individual effort. Nevertheless, it appears that industry should recognize the individuality and creativeness of the engineer by establishing an incentive apart from salary and promotion considerations. To a degree this notion has been practiced in Russia where not only professional recognition but economic well-being is put on a competitive basis above the routine of normal work.

This idea is not new and had been put to a test on a large scale by the Government by the passage of the Awards Act of 1954. The Act permitted departments to make awards either cash or honorary for useful suggestions or superior performance. The number of such awards made during 1955 through 1957 for suggestions adopted was 197,750. The total cash outlay for such awards amounted to 6.1 million. For superior performance the number of awards was 68,250. The estimated savings for Government operations in both categories was 312.2 million.

This program was clearly a success even though some of the suggestions or performance might have been of doubtful character. There is some question, however, whether such awards stimulate scientific creativity and improve the over-all morale of the organization. In general, employee reaction has been favorable toward such awards. An interesting sidelight of employee reaction pointed out that where an award was made cash was preferred to an honorary award. It appears, therefore, that incentives are worthwhile and that the scientific community is in favor of this procedure. Incentive plans have been used in industry but mainly in those productive areas where an easily measured result in a given time could be evaluated. Very little has been done in establishing proper incentives for research and engineering development work that involves creative effort as well as intangibles. Today, when so much of our national effort is involved with scientific research and engineering development on a broad front and unprecedented scale some means should be devised to carry out this work more efficiently and within the practical limits of our ability to pay for it.

Within the framework of "cost plus" type of research and development work, serious consideration should be given to a plan that would encourage the engineer or scientist to become a positive business factor as well as a technical factor towards achieving successful research goals. Given the opportunity of approaching an engineering problem both from a scientific and business aspect, the group responsible for the successful performance of the task within budgetary limits might welcome an incentive award for completing the project on time. The technical staff so charged would be acquainted not only with the technical problems but also with the costs allocated to their effort. While this knowledge may be burdensome in successfully prosecuting a development program, it also carries with it a highly desirable reward aspect. Any such incentive plan requires that the initial planning and goals must be established with the help of scientific personnel and that all objectives must be realistic so far as time schedules and budgets are concerned. The incentive award would be based upon achieving the target and in addition sharing in cost savings that would be generated by efficient management between the scientific and business administration of the company. In this atmosphere, the engineer, scientist or groups of technical personnel would view their work in a somewhat different light. Having been part of the planning and having a business stake in the program apart from salary considerations, the individual or scientific team would improve their own efficiency to meet the challenge of economic incentive.

Contractually, there are a number of problems to be overcome, not the least of which is the admissibility of incentive awards. Here too, the concept is not entirely new. In the past, the Government through its contracting officers have from time to time offered incentives in fixed price type contracts. Expanding this idea to "cost plus" type contracts to include both the contractor and the project team might provide a better research and development atmosphere for more efficient accomplishment.

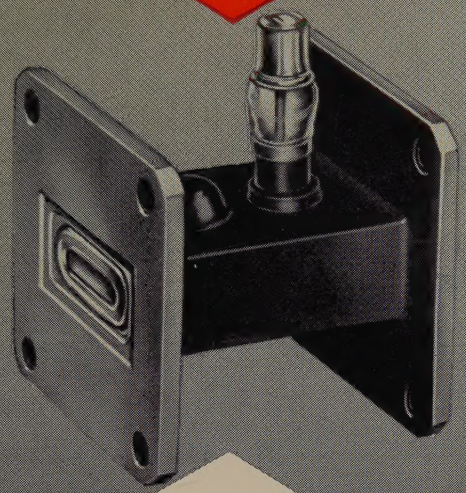
Some observers have felt that there is a large segment of scientific personnel who are not willing to assume the business burden regardless of its reward. Some have argued that in the event the technical group does not achieve its incentive goal the morale of the organization would suffer and that instead of improving conditions, the opposite would result. Indeed, it must be recognized that any type incentive arrangement requires a well planned program suitable to a particular company's needs and personnel to avoid ill effects or other disruptive influences.

Experience has shown, however, that the majority of technical personnel are in favor of incentive awards and regard such a plan as a measure of the confidence of management in the technical staff towards the successful achievement of technical and economic goals. The incentive plan to be successful must limit the number of persons participating so that the individual within a group or project may feel the weight of his effort towards a particular goal. The practicability of accomplishing this depends upon the size of the project or program as well as the business management of the company.

An incentive plan properly executed may not only reduce over-all costs and conserve engineering effort but should also develop valuable economic concepts among technical personnel who are needed for leadership. In any case, it would seem that engineering organizations might do well to study the practicability of incentives in their respective organizations to determine whether or not substantial benefit may be achieved both for management and the individual engineer.

+125°C

a major



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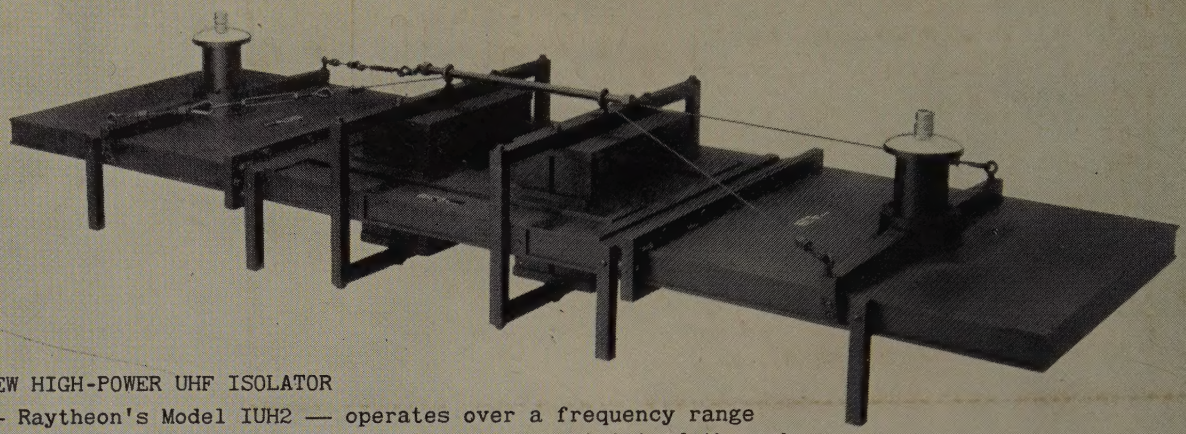

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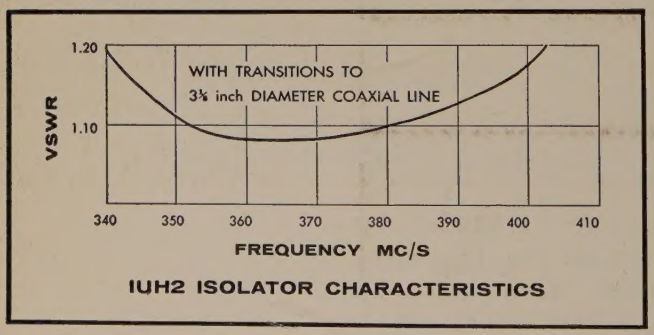
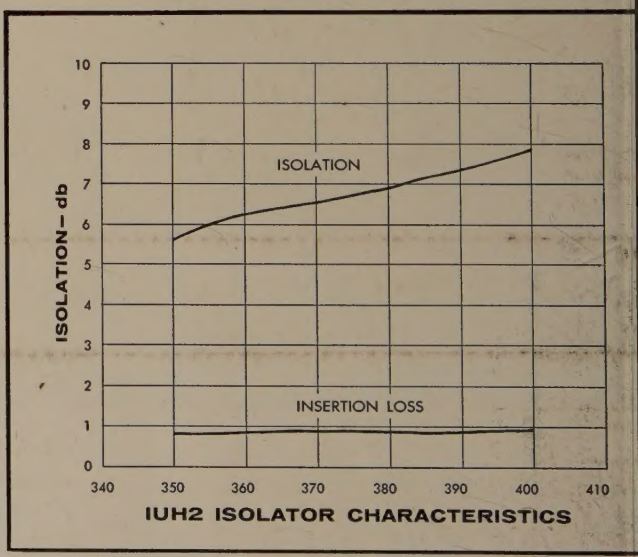


IUH2 ISOLATOR CHARACTERISTICS



IUH2 ISOLATOR CHARACTERISTICS

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